MISSOURI RIVER DESIGN STUDY

MRD HYDRAULIC LABORATORY SERIES

REPORT NO. 6

LABORATORY INVESTIGATION OF THE JUNCTION LOSSES AT THE KANSAS AND MISSOURI RIVER CONFLUENCE

MEAD HYDRAULIC LABORATORY
MEAD, NEBRASKA

U. S. ARMY ENGINEER DISTRICT, OMAHA
U. S. ARMY ENGINEER DISTRICT, KANSAS CITY
MISSOURI RIVER DIVISION, OMAHA

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Presented in this report are the results of a fixed-bed model study for determining the junction loss at the confluence of the Kansas and Missouri rivers. the study was performed at the Mead Hydraulic Laboratory by personnel of the Hydro-Sediment section of the Omaha District, corps of engineers, with guidance provided by the Kansas City District, and under the general supervision of the Missouri River Division.

Prediction of the junction loss at the confluence of two streams is, at best, an estimate. the determination of water surface profiles at the junction of two streams includes allowances for internal energy losses due to momentum exchange and concentrated friction at the confluence of the streams. these allowances would then be reflected in the resulting backwater profiles upstream of the confluence

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LABORATORY INVESTIGATION OF THE JUNCTION LOSS AT THE KANSAS-MISSOURI RIVER CONFLUENCE

Conducted at
Mead Hydraulic Laboratory
Mead, Nebraska

U. S. Army Engineer District, Omaha, Nebraska
U. S. Army Engineer District, Kansas City, Missouri
Missouri River Division, Omaha, Nebraska

August 1971

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1. U. S. Army Corps of Engineers, Missouri River Division, "Operation and Function of the Mead Hydraulic Laboratory, "MRD Hydraulic Laboratory Series Report No. 1, March 1969.

2. Taylor, "Flood Characteristics at Rectangular Open-Channel Junctions," ASCE Transactions, 1944.

3. Rouse, Engineering Hydraulics, John Wiley and Sons, Inc., New York, 1950.

4. The Committee of the Hydraulics Division on Hydraulic Research, "Hydraulic Models," ASCE Manual No. 25, July 23, 1942.

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6. U. S. Army Corps of Engineers, Kansas City District, "Flood Protection Project, Kansas River Basin," Design Memorandum No. 1, General, April 1965.

LIST OF SYMBOLS

Symbol	Description
D	Mean depth = Hydraulic radius.
g	Acceleration of gravity.
L	Any horizontal length.
m	Subscript referring to model.
n	Manning's roughness coefficient.
p	Subscript referring to prototype.
q	Unit discharge.
Q_T	Discharge below Kansas and Missouri River Confluence.
Q_M	Missouri River discharge above Confluence.
Q_K	Kansas River discharge above Confluence.
Q_{Kov}	Kansas River flood flows that entered Missouri River below Confluence.
r	Subscript referring to ratio model:prototype.
s	Slope.
$\bar{V}$	Mean velocity in any vertical.
V	Mean velocity in the cross section.
α	Energy coefficient for velocity head correction for nonuniform velocity distribution = $\frac{\sum (q \cdot \bar{V}^2)}{Q \cdot V^2}$
β	Momentum coefficient - momentum correction due to nonuniform velocity distribution = $\frac{\sum (q \cdot \bar{V})}{Q \cdot V}$

LABORATORY INVESTIGATION OF THE JUNCTION LOSS
AT THE KANSAS-MISSOURI RIVER CONFLUENCE

INTRODUCTION

1. Presented in this report are the results of a fixed-bed model study for determining the junction loss at the confluence of the Kansas and Missouri Rivers. The study was performed at the Mead Hydraulic Laboratory(1) by personnel of the Hydro-Sediment Section of the Omaha District, Corps of Engineers, with guidance provided by the Kansas City District, and under the general supervision of the Missouri River Division.

2. Prediction of the junction loss at the confluence of two streams is, at best, an estimate (2,3). The determination of water surface profiles at the junction of two streams includes allowances for internal energy losses due to momentum exchange and concentrated friction at the confluence of the streams. These allowances would then be reflected in the resulting backwater profiles upstream of the confluence.

PURPOSE OF STUDY

3. The purpose of the investigation was to determine the magnitude of the junction loss at the confluence of the Kansas and Missouri Rivers in order to insure the proper elevation of the levees located near the junction of the Kansas and Missouri Rivers in Kansas City, Kansas. Junction losses for the design flood, using methods developed by Taylor(2), were found to be 1.9 feet. Water surface profiles obtained during the 1951 and 1952 floods appear to substantiate this estimate. However, because of the critical location of the Kansas City levees, and the uncertainty of the prototype data, it was decided to verify the computations using a fixed-bed model. The purpose of the model study was to: (a) determine the magnitude of the loss; (b) develop a structure at the confluence which would be effective in reducing the magnitude of the junction loss; and (c) determine if structures installed in the navigation channel near the confluence would retard Kansas River design flows, and thus jeopardize the effectiveness of the Kansas River levees and floodwalls.

DESCRIPTION OF THE KANSAS-MISSOURI RIVER CONFLUENCE

4. The Kansas River enters the Missouri River in Kansas City, Kansas, at Missouri River mile 367.5 (1960 river mile). It enters on the concave bank (outside) of an extremely sharp Missouri River bend called the Kansas River Bend (see Figure 1). The Kansas River has a drainage area of 60,060 square miles, with about 14 percent of the area having no existing or authorized flood control reservoirs. The largest storm of record in the Kansas basin occurred in 1951, when the Kansas River peaked with an estimated flow of 510,000 cfs at Kansas City, coincident with a flow of 63,000 cfs in the Missouri River. It was estimated that 100,000 cfs of the Kansas River flow overtopped the Kansas River right bank floodwall during this flood, causing large scale flooding of the central industrial district. These flood waters entered the Missouri River channel by overtopping the Missouri River right bank floodwall between the confluence of the two streams and the Hannibal Bridge. Figures 2 and 3 are aerial photos of this region during and after the 1951 flood. In 1952, a flood of 60,000 cfs was recorded on the Kansas River, coincident with 400,000 cfs downstream in the Missouri River. Although this event did not cause flooding in Kansas City, it did provide valuable prototype data useful for model verification.

DESIGN DISCHARGES

5. The design discharge for the Kansas River levees is 390,000 cfs, with a coincident discharge of 220,000 cfs in the Missouri River. The resulting design flow below the confluence is 610,000 cfs. Additional storage provided in the basin since 1951 would have permitted this levee design to safely pass the recorded 1951 flood.

MODEL DESIGN

6. The first consideration in the selection of the model scales, was to determine the length of the reach to be investigated in the model. Sufficient distances were provided at both the upper and lower segments of the model to minimize the influences of the entrance and exit conditions. A 1:150 horizontal scale ratio was selected, as it was the largest that would permit the desired model to fit within the confines of the laboratory. The selected vertical scale ratio was 1:75, thus resulting in a 2:1 vertical-to-horizontal distortion. Adherance to the Froude criteria[4] without distortion, $(V^2/gD)_m = (V^2/gD)_p$, would have resulted in shallow depths, low velocities, and extremely flat water surface slopes, thus making it difficult to obtain reliable model measurements.

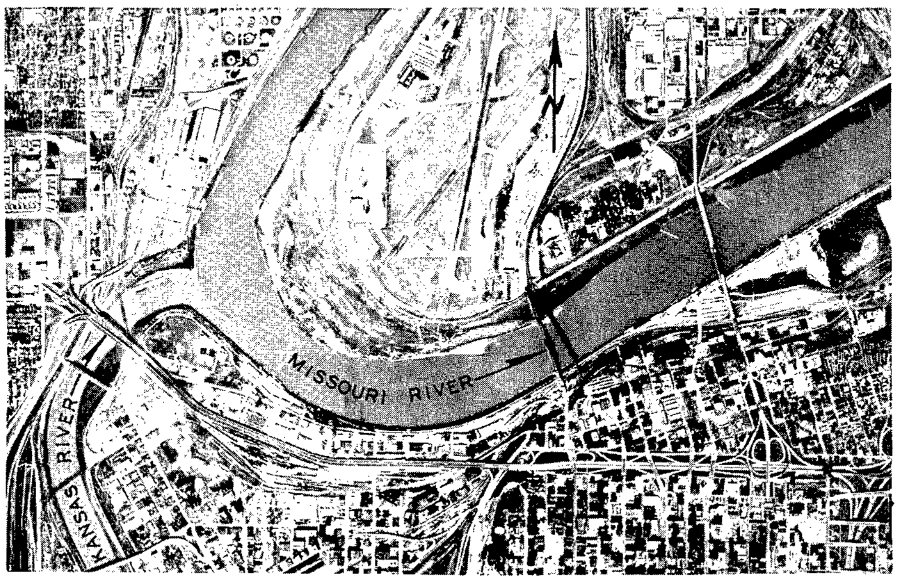


Figure 1. Photograph of the Kansas-Missouri River confluence. Photo indicates the approximate limits of the region used in the model investigation.

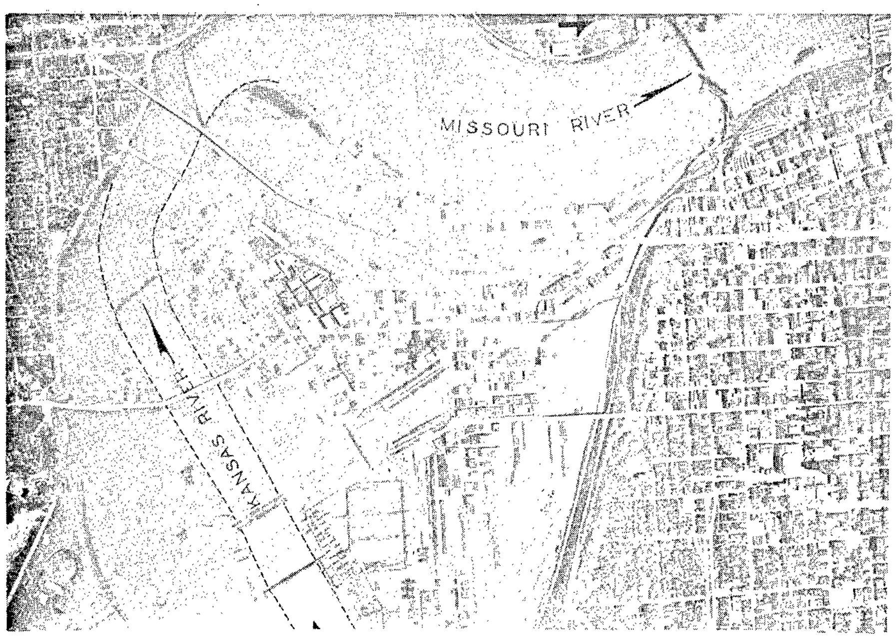


Figure 2. Aerial view of Kansas-Missouri River confluence. Area photographed during 1951 flood.

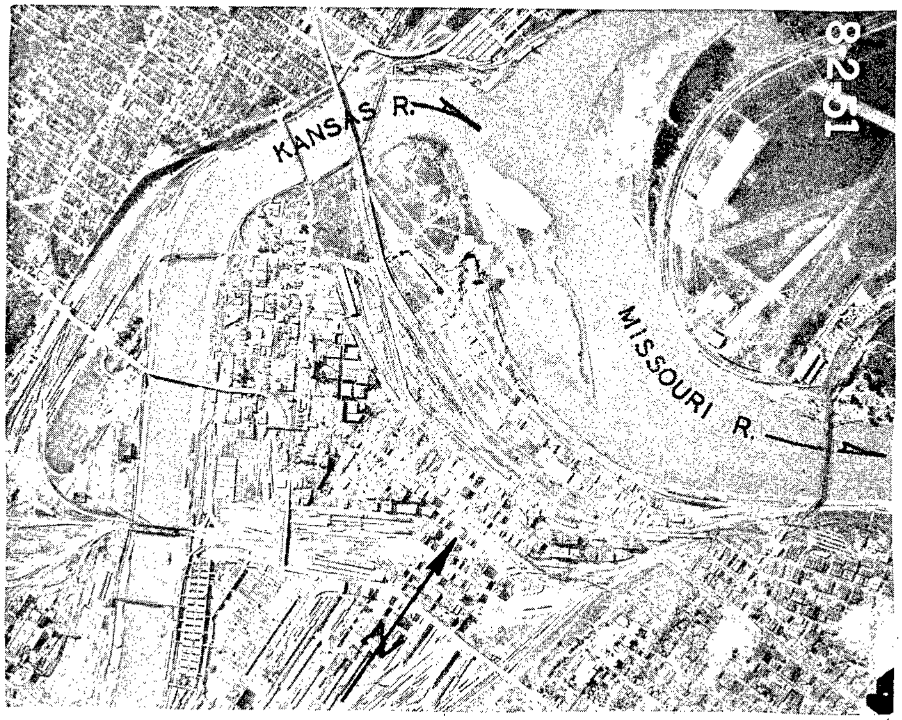


Figure 3. Photograph of the Kansas-Missouri confluence after the 1951 flood. Note large amount of deposition immediately downstream of junction in Missouri River channel.

7. Computations using prototype data obtained during the 1951 flood indicated the prototype channel roughness (Manning's "n") to be about 0.02. Further computations based on a combination of prototype dimensions and selected model scale ratios, indicated the model "n" should be .015. A test section was constructed in the laboratory to estimate the probable roughness of the model channel. These tests indicated that the selected model roughness would be close to the desired value; however, minor adjustments in the roughness were later found to be necessary. The final selected model scale relationships are shown in Table 1.

TABLE 1.

SCALE RATIOS - MODEL:PROTOTYPE

Parameter						
Length ratio	=	L_r		L_r	=	1:150
Depth ratio	=	D_r		D_r	=	1:75
Velocity ratio	=	V_r	=	$D_r^{1/2}$	=	1:8.66
Discharge ratio	=	Q_r	=	$L_r D_r^{3/2}$	=	1:97,400
Slope ratio	=	S_r	=	D_r/L_r	=	1:0.5
Roughness (Manning's "n")	=	n_r	=	$D_r^{2/3}/L_r^{1/2}$	=	1:1.45

MODEL CONSTRUCTION

8. The study was conducted using a recirculating, fixed-bed flume. Plate 1 shows the model layout and Figures 4 and 5 are photographs of the model in operation. The flume used in this investigation was previously used for a movable-bed study of navigation structures in the same reach. "MRD Hydraulic Laboratory Series Report No. 1," describes the methods used to construct the model basin and the water recirculating system. The system was equipped to deliver water at three locations in the basin; the upper end of the Missouri River channel, the upper end of the Kansas River channel, and along the right bank flood wall at Missouri River mile 367, as shown on Plate 1. Each water discharge line contained a gate valve, thus permitting fine adjustments necessary to balance flows between the various delivery points.

9. After the selection of the proper scale ratios, prototype quantities such as channel cross sections and water-surface profiles were reduced to model dimensions, and constructed in the basin. The original model was constructed to represent the channel geometry existing at the time of the 1951 flood (see Figure 3). Subsequent tests of the Missouri River in the vicinity of the confluence were reshaped to represent 1968 channel conditions. Plate 2 shows the location of the measured model cross sections, and Plates 3 and 4 are plots of the cross sections constructed in the basin.

10. The model channel was originally formed in sand to the proper dimensions through the use of metal templates. These templates were

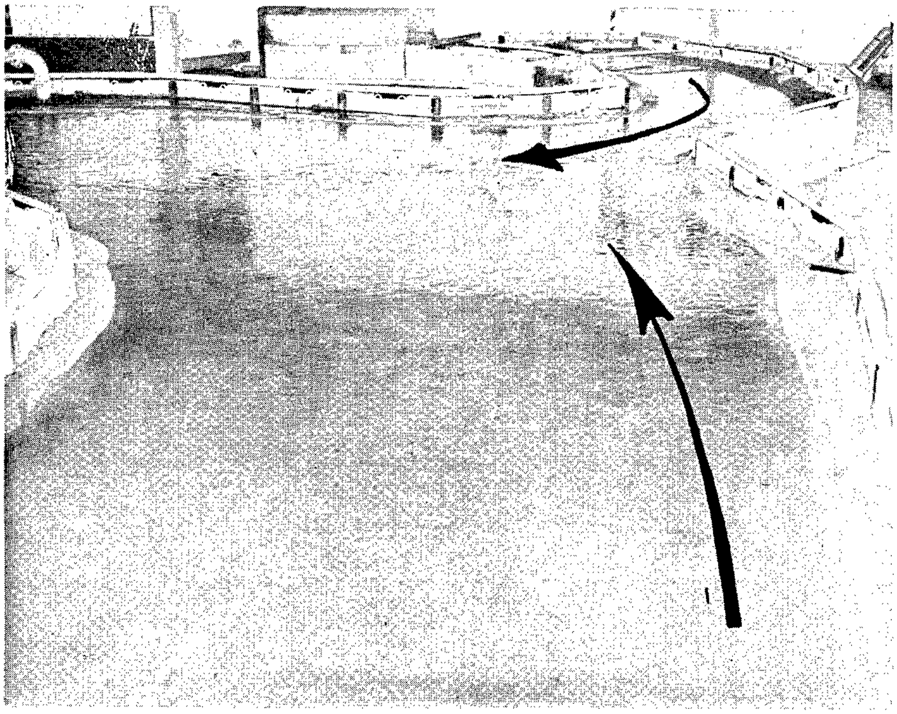


Figure 4. View of model in operation, looking downstream on Missouri River toward confluence.

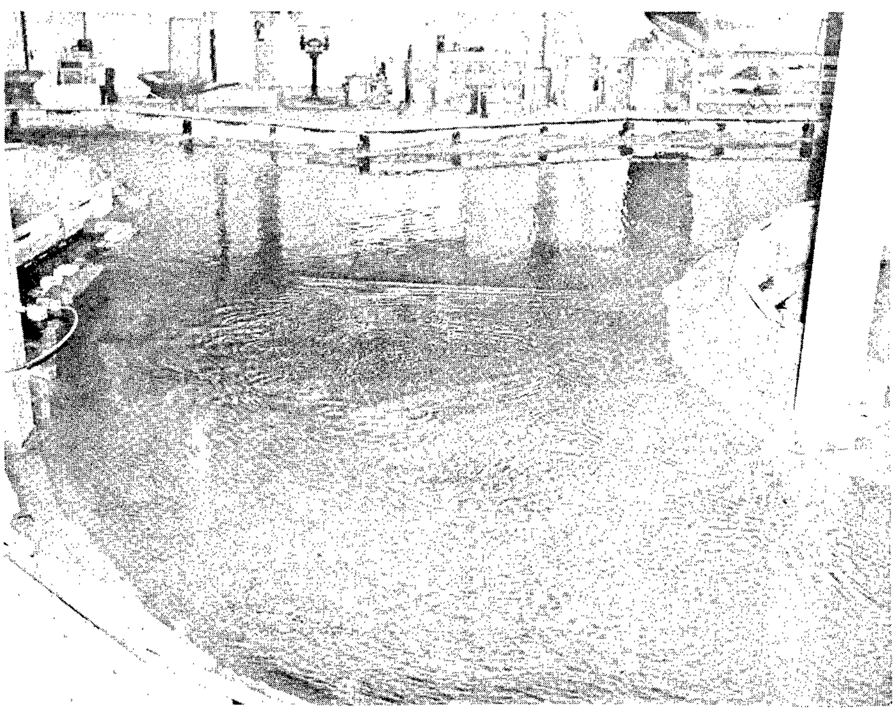


Figure 5. View of model while operating, looking upstream on Missouri River toward confluence.

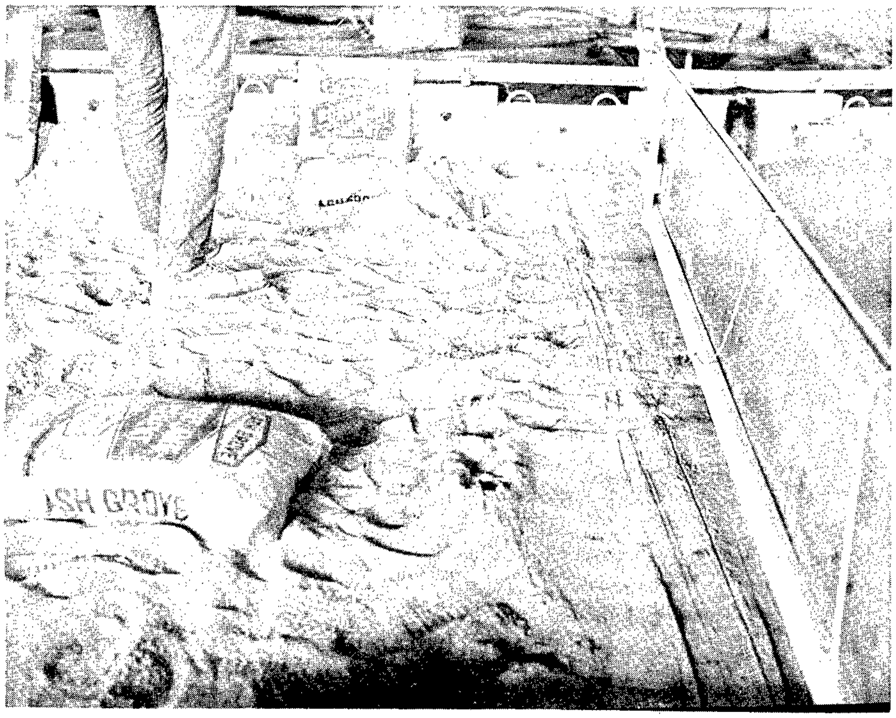
suspended from level steel rails mounted above the concrete "T" sections which formed the basin walls. A thin layer of dry cement was then placed on the bed surface and thoroughly mixed into the top 1-1/2 to 2 inches of sand (see Figures 6 and 7). After mixing the cement into the sand, the channel was reshaped with the templates and moistened with a fine mist of water until the top two inches of the channel bed was saturated. The resultant bed surface exhibited a texture similar to that of the original sand channel, and had sufficient strength to support the weight of a man.

MODEL MEASUREMENTS

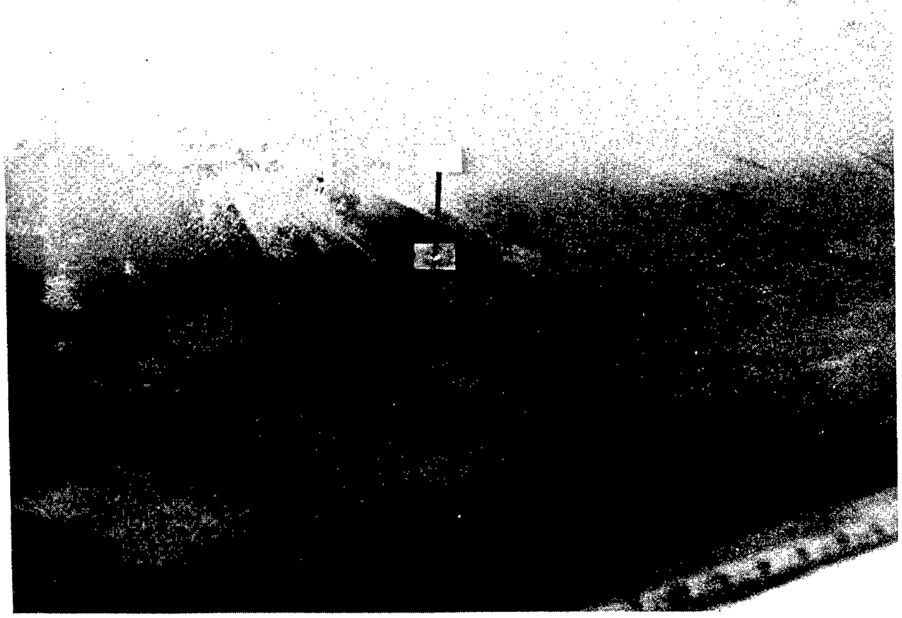
11. The rate of flow at each of the three delivery points in the model was controlled by adjusting either the variable speed pumps or the gate valves in each of the delivery lines. Water manometers were used to determine the rates of flow by measurements of differential pressures across venturi-type meters installed in the water delivery lines.

12. Water surface elevations in the model were recorded by monitoring the hydrostatic pressure from piezometer taps set flush with the channel bed (see Figures 8 and 9). These twenty-nine taps were connected to a bank of stilling wells located outside the model basin with plastic tubes. The water surface elevation in each stilling well was determined through the use of the point gage illustrated in Figure 9. Water surface elevations were recorded on each bank throughout the Kansas River Bend. The location of each tap is shown on Plate 2. Presented in Table II are the recorded model elevations for each of the profiles illustrated in this report. Plate 5 illustrates a typical water surface profile and shows the difference in the water surface elevations between the left and right bank.

13. Lateral flow distributions were determined at six model locations by observing point velocities across the channel width. The average velocity in each vertical was determined by measuring the point velocity at six-tenths of the channel depth. These measurements were made at 0.4-foot intervals across the channel width using a pygmy current meter. These observations were accomplished for flows representing the design flow of 610,000 cfs and were used to determine the energy (α) and momentum (β) distribution coefficients presented in Table III. The energy distribution coefficients were used in computing energy grade lines. Two examples are shown on Plate 5. The energy grade elevation was determined by adding the velocity head ($\alpha V^2/2g$) to the observed water surface elevation. The momentum distribution coefficients were used in computing the junction losses. The computational procedures used are discussed in paragraph 26.



Figures 6 and 7. Bed of model was stabilized by spreading a thin layer of cement on surface of preshaped sand bed (upper photo) and thoroughly mixed into the top two inches of sand (lower photo).



Figures 8 and 9. Piezometer taps were placed throughout the flume (above) and connected to a bank of stilling wells (below) by plastic tubes. Water surface elevations were then recorded in each stilling well with a point gage.

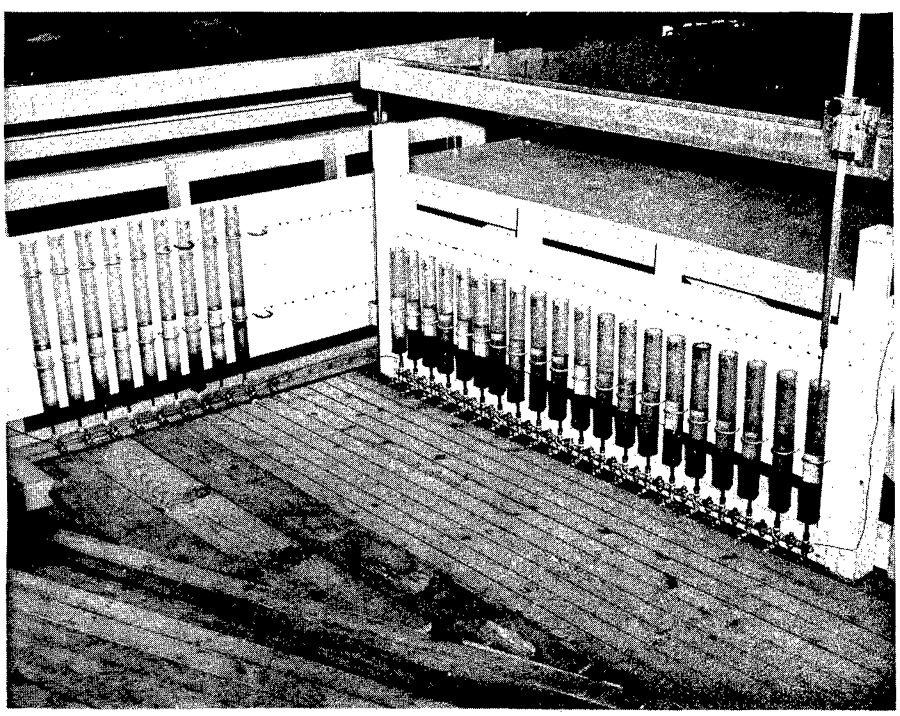


TABLE II

OBSERVED MODEL WATER SURFACE ELEVATIONS

1951 CHANNEL

Run Number	12a	12d	12e	12g	8a	8b	8d	8c	9a	9b	9d	9c	10a	10b	10d	10c	6T3	6v
Model Discharge in C.F.S.	6.26	6.26	6.26	6.26	5.13	5.13	5.13	5.13	4.10	4.10	4.10	4.10	3.08	3.08	3.08	3.08	5.88	4.10
Q_M	100%	50%	34%	0%	100%	50%	34%	0%	100%	50%	34%	0%	100%	50%	34%	0%	11%	100%
Q_K	0%	50%	66%	100%	0%	50%	66%	100%	0%	50%	66%	100%	0%	50%	66%	100%	89%	0%
Piezometer Number																		
1	0.694	0.693	0.691	0.695	0.648	0.646	0.644	0.643	0.591	0.585	0.583	0.581	0.533	0.503	0.524	0.509	0.670	0.593
2	0.678	0.688	0.689	0.693	0.633	0.642	0.642	0.639	0.579	0.583	0.583	0.579	0.520	0.500	0.523	0.508	0.670	0.578
3	0.679	0.690	0.689	0.691	0.633	0.643	0.641	0.642	0.580	0.583	0.583	0.583	0.520	0.501	0.523	0.509	0.670	0.580
4	0.674	0.690	0.689	0.678	0.627	0.642	0.641	0.634	0.572	0.583	0.582	0.574	0.512	0.500	0.521	0.505	0.669	0.573
5	0.678	0.692	0.689	0.685	0.632	0.644	0.642	0.636	0.577	0.583	0.583	0.573	0.516	0.501	0.523	0.505	0.669	0.578
6	0.682	0.692	0.690	0.689	0.635	0.644	0.642	0.640	0.579	0.585	0.583	0.578	0.519	0.501	0.522	0.507	0.670	0.581
7	0.673	0.688	0.686	0.687	0.626	0.641	0.639	0.638	0.571	0.582	0.582	0.578	0.509	0.499	0.521	0.508	0.665	0.571
8	0.680	0.687	0.683	0.674	0.635	0.641	0.637	0.628	0.579	0.582	0.578	0.570	0.519	0.500	0.519	0.503	0.658	0.578
K 9	0.683	0.685	0.683	0.705	0.637	0.640	0.638	0.643	0.580	0.582	0.581	0.592	0.520	0.501	0.523	0.523	0.668	0.582
K 10	0.684	0.679	0.675	0.667	0.637	0.634	0.629	0.623	0.580	0.576	0.572	0.565	0.519	0.498	0.513	0.500	0.656	0.581
K 11	0.684	0.682	0.680	0.667	0.637	0.637	0.634	0.630	0.579	0.578	0.575	0.571	0.519	0.499	0.516	0.502	0.663	0.581
K 12	0.684	0.684	0.682	0.683	0.637	0.639	0.636	0.633	0.580	0.580	0.578	0.575	0.519	0.500	0.517	0.505	0.665	0.582
13	0.679	0.681	0.682	0.679	0.632	0.636	0.633	0.623	0.575	0.577	0.575	0.567	0.513	0.498	0.515	0.501	0.673	-
14	0.684	0.680	0.676	0.669	0.637	0.636	0.632	0.626	0.580	0.577	0.573	0.569	0.517	0.497	0.515	0.502	0.657	0.581
15	0.662	0.677	0.675	0.675	0.618	0.633	0.630	0.628	0.564	0.575	0.573	0.573	0.506	0.496	0.515	0.503	0.665	0.576
16	0.674	0.678	0.676	0.666	0.628	0.634	0.631	0.622	0.574	0.576	0.574	0.567	0.511	0.497	0.515	0.501	0.660	0.574
17	0.680	0.680	0.676	0.668	0.633	0.636	0.631	0.622	0.576	0.577	0.574	0.567	0.514	0.498	0.515	0.501	0.658	0.578
18	0.671	0.674	0.672	0.665	0.625	0.630	0.628	0.620	0.570	0.573	0.570	0.564	0.509	0.495	0.511	0.499	0.655	0.570
19	0.676	0.679	0.676	0.668	0.630	0.635	0.632	0.623	0.573	0.576	0.574	0.567	0.512	0.497	0.515	0.500	0.656	0.575
20	0.662	0.664	0.662	0.657	0.618	0.620	0.619	0.613	0.564	0.565	0.564	0.560	0.505	0.493	0.505	0.495	0.645	0.565
21	0.668	0.671	0.672	0.674	0.622	0.626	0.626	0.626	0.567	0.570	0.569	0.569	0.506	0.493	0.511	0.501	0.650	0.567
22	0.643	0.642	0.641	0.615	0.600	0.601	0.601	0.579	0.549	0.548	0.548	0.535	0.490	0.483	0.490	0.479	0.622	0.549
23	0.643	0.642	0.643	0.628	0.600	0.602	0.602	0.591	0.549	0.548	0.549	0.539	0.490	0.483	0.491	0.482	0.627	0.550
24	0.638	0.638	0.638	0.628	0.595	0.597	0.596	0.590	0.544	0.545	0.545	0.539	0.486	0.481	0.487	0.481	0.623	0.545
25	0.637	0.636	0.637	0.632	0.594	0.596	0.597	0.592	0.543	0.543	0.543	0.541	0.484	0.480	0.484	0.481	0.623	0.544
26	0.629	0.627	0.630	0.628	0.588	0.589	0.590	0.588	0.538	0.537	0.538	0.437	0.480	0.477	0.479	0.478	0.616	0.538
27	0.625	0.623	0.624	0.625	0.584	0.584	0.585	0.585	0.534	0.534	0.534	0.534	0.476	0.475	0.475	0.476	0.612	0.534
28	0.616	0.612	0.613	0.615	0.574	0.573	0.576	0.576	0.526	0.524	0.526	0.522	0.468	0.471	0.466	0.469	0.602	0.526
29	0.609	0.606	0.608	0.610	0.569	0.567	0.571	0.571	0.520	0.518	0.520	0.521	0.462	0.468	0.459	0.465	0.596	0.520

1968 CHANNEL

Run Number	112a	112d	112e	112g	108a	108b	108d	108c	109a	109b	109d	109c	110a	110b	110d	110c	106v	113a
Model Discharge in C.F.S.	6.26	6.26	6.26	6.26	5.13	5.13	5.13	5.13	4.10	4.10	4.10	4.10	3.08	3,08	3.08	3.08	4.10	0.40
Q_M	100%	50%	34%	0%	100%	50%	34%	0%	100%	50%	34%	0%	100%	50%	34%	0%	100%	100%
Q_K	0%	50%	66%	100%	0%	50%	66%	100%	0%	50%	66%	100%	0%	50%	66%	100%	0%	0%
Piezometer Number																		
1	0.704	0.707	0.701	0.709	0.656	0.654	0.654	0.658	0.604	0.601	0.598	0.600	0.540	0.509	0.526	0.533	0.603	0.264
2	0.690	0.703	0.699	0.709	0.642	0.649	0.651	0.656	0.591	0.597	0.597	0.598	0.530	0.507	0.525	0.532	0.591	0.262
3	0.692	0.703	0.700	0.703	0.645	0.652	0.653	0.654	0.592	0.596	0.596	0.597	0.529	0.507	0.525	0.534	0.592	0.261
4	0.687	0.704	0.700	0.702	0.638	0.651	0.653	0.653	0.585	0.596	0.595	0.596	0.520	0.506	0.525	0.531	0.585	0.240
5	0.688	0.704	0.700	0.703	0.641	0.652	0.653	0.654	0.588	0.596	0.596	0.597	0.523	0.507	0.525	0.531	0.587	0.238
6	0.690	0.705	0.700	0.706	0.642	0.652	0.654	0.654	0.588	0.597	0.597	0.598	0.525	0.507	0.525	0.532	0.588	0.237
7	0.680	0.697	0.695	0.707	0.633	0.646	0.649	0.656	0.581	0.591	0.593	0.602	0.517	0.503	0.523	0.538	0.580	-
8	0.692	0.701	0.694	0.695	0.645	0.650	0.649	0.644	0.592	0.595	0.593	0.591	0.527	0.507	0.523	0.528	0.592	0.239
K 9	0.693	0.696	0.690	0.707	0.646	0.647	0.646	0.649	0.593	0.594	0.592	0.601	0.528	0.507	0.524	0.542	0.593	0.237
K 10	0.693	0.691	0.682	0.676	0.646	0.642	0.638	0.629	0.592	0.588	0.583	0.576	0.528	0.504	0.515	0.517	0.593	0.237
K 11	0.693	0.695	0.687	0.686	0.646	0.644	0.642	0.637	0.592	0.590	0.586	0.583	0.528	0.505	0.517	0.519	0.593	0.237
K 12	0.693	0.697	0.689	0.692	0.646	0.646	0.645	0.643	0.592	0.591	0.588	0.587	0.528	0.505	0.519	0.523	0.592	0.237
13	0.685	0.688	0.682	0.676	0.638	0.639	0.637	0.631	0.582	0.584	0.583	0.579	0.517	0.500	0.514	0.519	0.582	0.238
14	0.695	0.692	0.683	0.678	0.647	0.643	0.639	0.632	0.592	0.588	0.584	0.579	0.527	0.503	0.516	0.518	0.592	0.240
15	0.668	0.681	0.680	0.688	0.624	0.631	0.634	0.634	0.570	0.577	0.578	0.578	0.508	0.494	0.507	0.512	0.570	-
16	0.680	0.686	0.682	0.681	0.631	0.635	0.635	0.633	0.576	0.580	0.579	0.578	0.510	0.495	0.508	0.512	0.576	0.237
17	0.683	0.689	0.683	0.678	0.636	0.639	0.639	0.632	0.580	0.584	0.583	0.579	0.513	0.494	0.514	0.517	0.579	0.236
18	0.666	0.670	0.668	0.670	0.619	0.622	0.622	0.632	0.565	0.568	0.569	0.567	0.500	0.488	0.497	0.499	0.565	0.219
19	0.673	0.679	0.677	0.680	0.625	0.629	0.630	0.630	0.570	0.574	0.574	0.573	0.505	0.491	0.503	0.504	0.571	0.227
20	0.657	0.659	0.657	0.654	0.612	0.613	0.613	0.608	0.559	0.560	0.560	0.550	0.496	0.485	0.491	0.487	0.558	0.220
21	0.664	0.666	0.665	0.665	0.617	0.618	0.619	0.618	0.563	0.565	0.565	0.561	0.500	0.488	0.496	0.496	0.563	0.220
22	0.642	0.639	0.637	0.622	0.599	0.597	0.594	0.588	-	0.548	0.548	0.541	0.491	0.482	0.487	0.485	0.548	0.218
23	0.642	0.639	0.638	0.627	0.599	0.597	0.597	0.590	0.547	0.547	0.548	0.542	0.488	0.481	0.485	0.484	0.547	0.217
24	0.638	0.637	0.636	0.628	0.595	0.595	0.595	0.591	0.542	0.545	0.546	0.542	0.484	0.478	0.482	0.482	0.544	0.214
25	0.637	0.636	0.637	0.632	0.594	0.594	0.595	0.592	0.543	0.545	0.545	0.542	0.483	0.478	0.481	0.480	0.543	0.212
26	0.630	0.628	0.630	0.627	0.588	0.588	0.588	0.587	0.537	0.539	0.541	0.537	0.478	0.475	0.477	0.476	0.538	0.210
27	0.625	0.624	0.625	0.623	0.584	0.584	0.584	0.584	0.534	0.536	0.536	0.534	0.475	0.474	0.475	0.473	0.534	0.207
28	0.615	0.613	0.615	0.612	0.576	0.576	0.575	0.577	0.526	0.528	0.529	0.526	0.468	0.469	0.468	0.465	0.526	0.197
29	0.614	0.606	0.610	0.607	0.568	0.566	0.564	0.566	0.519	0.523	0.523	0.520	0.461	0.467	0.462	0.457	0.523	0.181

NOTE: Piezometer locations are shown on Plate 2.

TABLE III
VELOCITY DISTRIBUTION COEFFICIENTS

MODEL RUN NUMBER	CHANNEL GEOMETRY	CHANNEL LOCATION RIVER MILE	CHANNEL LOCATION FLUME STATION	MODEL FLOW (cfs)	MODEL W.S. EL. (ft)	FLOW AREA (ft^2)	AVE. VEL. (ft/sec)	VEL. DIST. COEFFICIENTS α	VEL. DIST. COEFFICIENTS β	VEL. HEAD $\alpha V^2/2g$ (ft)	TOTAL ENERGY (ft)
12A	1951	367.86	27	6.26	0.677	6.10	1.03	1.15	1.05	0.020	0.697
		366.54	71	6.26	0.667	6.44	0.97	1.06	1.02	0.015	0.682
12C		367.86	27	4.10	0.691	6.15	0.67	1.20	1.07	0.008	0.699
		K0.13	K04	2.16	0.692	3.32	0.65	1.30	1.11	0.008	0.700
		366.54	71	6.26	0.677	6.57	0.95	1.17	1.06	0.017	0.694
12E		367.86	27	2.16	0.688	6.11	0.35	1.23	1.08	0.002	0.690
		K0.13	K04	4.10	0.682	3.26	1.26	1.28	1.08	0.031	0.713
		366.54	71	6.26	0.670	6.48	0.97	1.59	1.21	0.024	0.694
12G		K0.13	K04	6.26	0.684	3.27	1.93	1.42	1.18	0.082	0.766
		366.54	71	6.26	0.666	6.43	0.97	2.54	1.50	0.037	0.703
112A	1968	368.42	6	6.26	0.702	5.44	1.15	1.07	1.03	0.022	0.724
		367.86	27	6.26	0.686	6.17	1.02	1.11	1.04	0.019	0.705
		366.54	71	6.26	0.662	5.29	1.18	1.04	1.02	0.023	0.685
		365.82	96	6.26	0.636	4.71	1.33	1.37	1.12	0.038	0.674
		365.00	127	6.26	0.619	4.31	1.45	1.06	1.02	0.035	0.654
112C		367.86	27	4.10	0.700	6.37	0.64	1.14	1.04	0.007	0.707
		K0.13	K04	2.16	0.699	3.36	0.64	1.18	1.07	0.008	0.707
		366.54	71	6.26	0.668	5.37	1.17	1.06	1.02	0.022	0.690
112E		367.86	27	2.16	0.698	6.34	0.34	1.22	1.08	0.002	0.700
		K0.13	K04	4.10	0.687	3.29	1.25	1.41	1.16	0.034	0.721
		366.54	71	6.26	0.664	5.32	1.18	1.11	1.04	0.024	0.688
		365.82	96	6.26	0.634	4.69	1.33	1.41	1.15	0.039	0.673
		365.00	127	6.26	0.619	4.31	1.45	1.08	1.02	0.035	0.654
112G		K0.13	K04	6.26	0.693	3.32	1.88	1.43	1.16	0.079	0.772
		366.54	71	6.26	0.666	5.34	1.17	1.61	1.19	0.034	0.700

MODEL VERIFICATION

14. Preliminary tests were performed to observe the ability of the model to reproduce known prototype conditions. The 1951 flood, which was the largest flood on record, was selected as a condition to which the model was made to reproduce the prototype. The velocity and discharge scales were determined by applying the basic Froude relationships. Based on the prototype flows and the selected scale ratios, equivalent flows were introduced in the model at the three delivery points shown on Plate 1. Flows representing 63,000 cfs were introduced from the Missouri River, and 510,000 cfs from the Kansas River. Of the 510,000 cfs, 410,000 was introduced into the model near Kansas River mile 1.0. During the 1951 flood, approximately 100,000 second-feet overtopped the Kansas River right bank floodwall upstream of the model. Flows representing this 100,000 cfs were introduced into the model behind the Missouri River floodwall near mile 367 and allowed to overtop the floodwall and enter the Missouri River channel between miles 366.7 and 367.4.

15. The water surface elevation in the model was controlled by regulating the volume of water in the system. No tailgate of any kind was used to control the stage at the downstream limit of the model. Instead, the required water surface elevation at flume station 122 (mile 365.1) was maintained by controlling the volume of water in the system. The Kansas City gage rating curve, reduced to model dimensions and transposed downstream to flume station 122, was used to determine the proper stage (see Plate 6).

16. Verification of the model involved the adjustment of the model roughness so that the model water surface profiles would superimpose prototype profiles that had been reduced to model dimensions. For this verification, the Froude criteria was used to establish discharge and depth requirements. The model dimensions were determined from prototype measurements and the scale ratios presented in Table 1. Initial tests revealed that the roughness of the model bed was smoother than was indicated during the preliminary investigations. This resulted in relatively flat water surface profiles and shallow depths (see Plate 6). The bed roughness was increased by placing railroad spikes at the downstream model limits and intermittently throughout the entire channel length. This resulted in a satisfactory reproduction of the 1951 flood profile. The spacing of these spikes is shown in Figure 10. A further verification check was accomplished by satisfactorily reproducing the stages for the 1952 flood (see Plate 7).

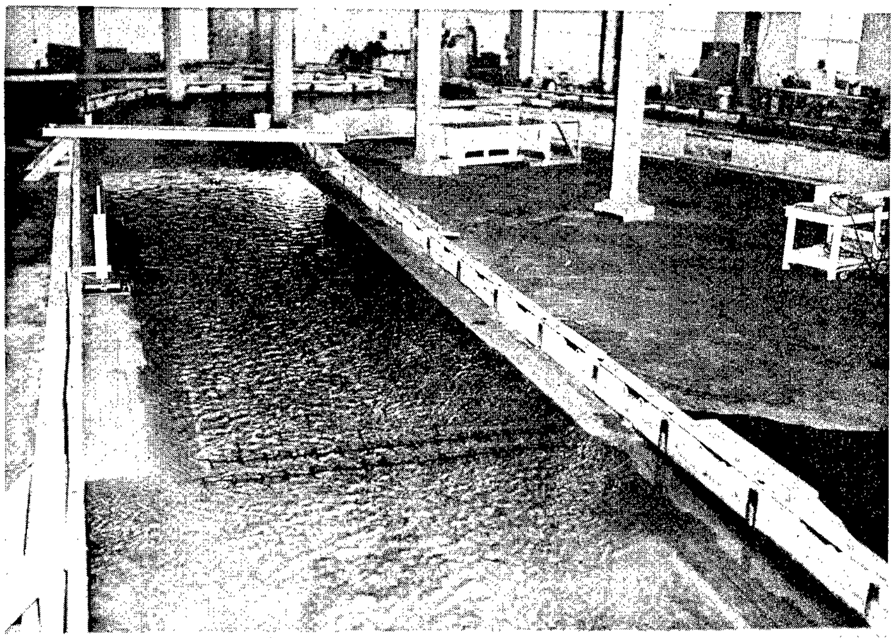


Figure 10. View of lower model reach looking upstream. Dark objects on channel bed are railroad spikes used to increase channel roughness.

17. The same flows were also used in a second series of tests in which the 1968 prototype channel conditions were reproduced in the flume. For these tests, the Missouri River channel near the mouth of the Kansas River (mile 366.54 to 367.64) was reshaped to represent the 1968 channel geometry. The upper and lower Missouri River reaches and the Kansas River segment of the model were not altered. The changes in the range profiles can be noted on Plate 4. An example of the corresponding change in the water surface profiles for flows used in the original tests, is shown on Plate 6. In this series of tests, the stage and discharge were also reduced to represent normal navigation flows of 40,000 cfs. These results are shown on Plate 7.

18. Model backwater curves were developed for the 1951 flood flows by computational procedures assuming Manning's roughness values of 0.012 and 0.015. In addition to the flood flows, profiles were also computed for discharges representing 400, 500, and 610 thousand cfs. The resulting profiles for three of these flows are presented on Plate 5. The comparisons with the measured model profiles indicate that the roughness in the model varied longitudinally.

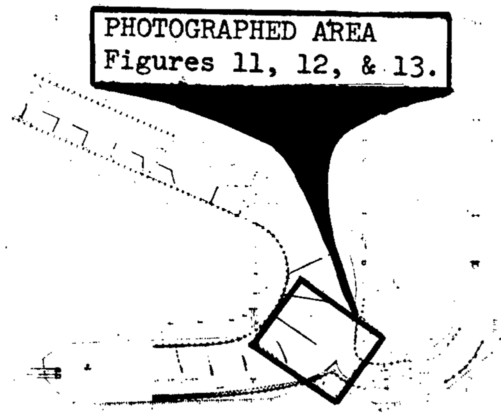
TEST PROCEDURE

19. After prototype conditions were satisfactorily reproduced in the model, efforts concentrated on the determination of the junction losses. Tests were conducted in which the total discharge below the confluence was held constant while the contribution from each river was varied. In the first test of this series, the entire flow was delivered from the Missouri River. In succeeding tests, Kansas River flows were then progressively increased and Missouri River flows correspondingly decreased, until finally a test was run with all flow coming from the Kansas River. The water surface profiles recorded for these tests are shown on Plates 8 and 9. Missouri River water surface elevations at the confluence were recorded and used to determine the junction loss. Tests were conducted representing total prototype discharges of 300, 400, 500, and 610 thousand cfs.

20. The direction of surface currents at the confluence was recorded for many of the model tests. These data were collected by photographing the movement of styrofoam pellets floating on the water surface. Examples of these are shown on Figures 11 and 12.

21. Attempts to reduce the junction loss were conducted in still another series of tests in which a sill placed at the confluence of the two streams was utilized. The purpose of the sill was to cause the flows from the Kansas and Missouri Rivers to merge at a lesser angle, thus reducing the loss in momentum and corresponding junction loss. Three sill lengths were tested for each of three sill crest elevations. A photograph of one of the test structures and the resulting surface currents, is shown on Figure 13. The water surface elevations near the confluence in both the Missouri and Kansas Rivers are presented in Table IV. Model flows for this series of tests represented the design flow of 610,000 cfs.

22. Table V lists all of the tests that were completed for the model study and indicates the channel geometry and discharge used with each test. The model stage at flume station 122 (mile 365.1) can be determined from the model rating curve on Plate 6. The water surface elevation at this station was controlled within $\pm$ 0.002 feet by use of an electronic instrument which controlled the amount of water to be added to or subtracted from the system so that the desired elevation was maintained.



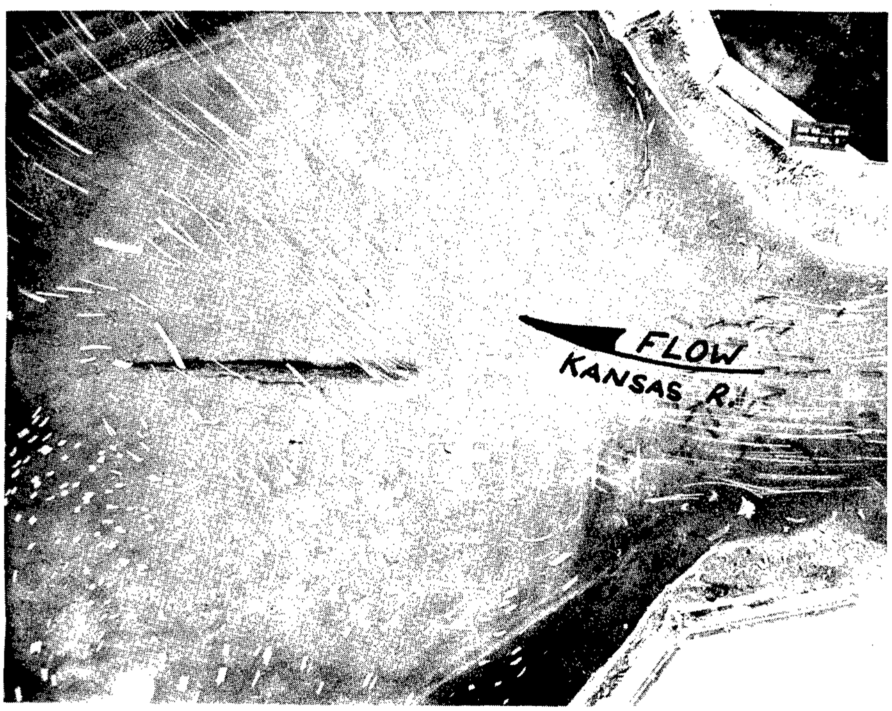


Figure 11. Photo shows the direction of the surface currents at the confluence of the two rivers during the reproduction of the 1951 flood. Kansas River flow enters the Missouri at the extreme right.

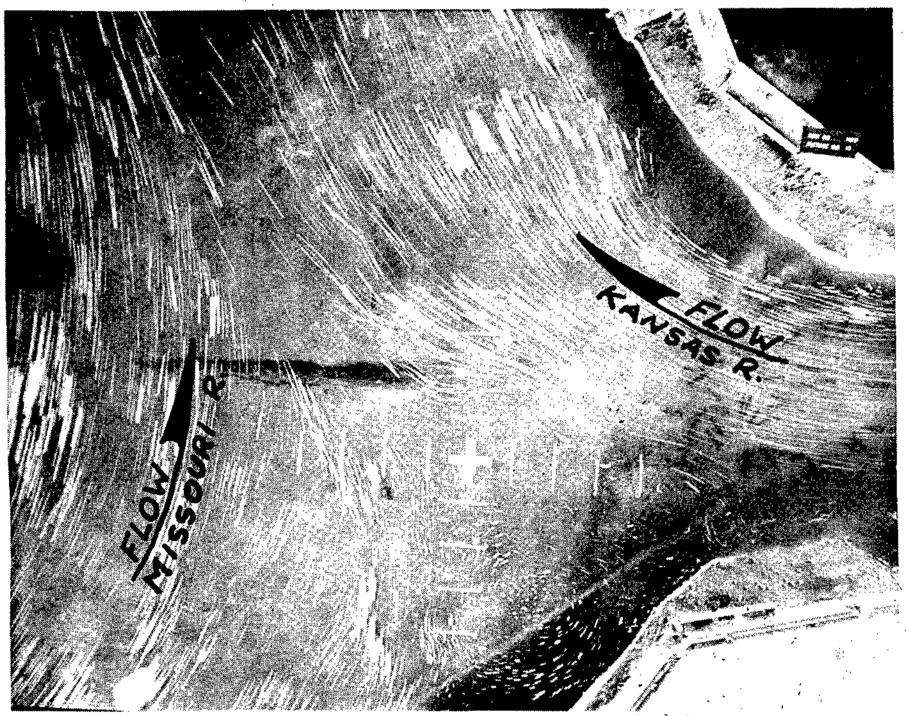


Figure 12. Photograph of surface currents at the confluence for flows evenly divided between the Missouri and Kansas Rivers.

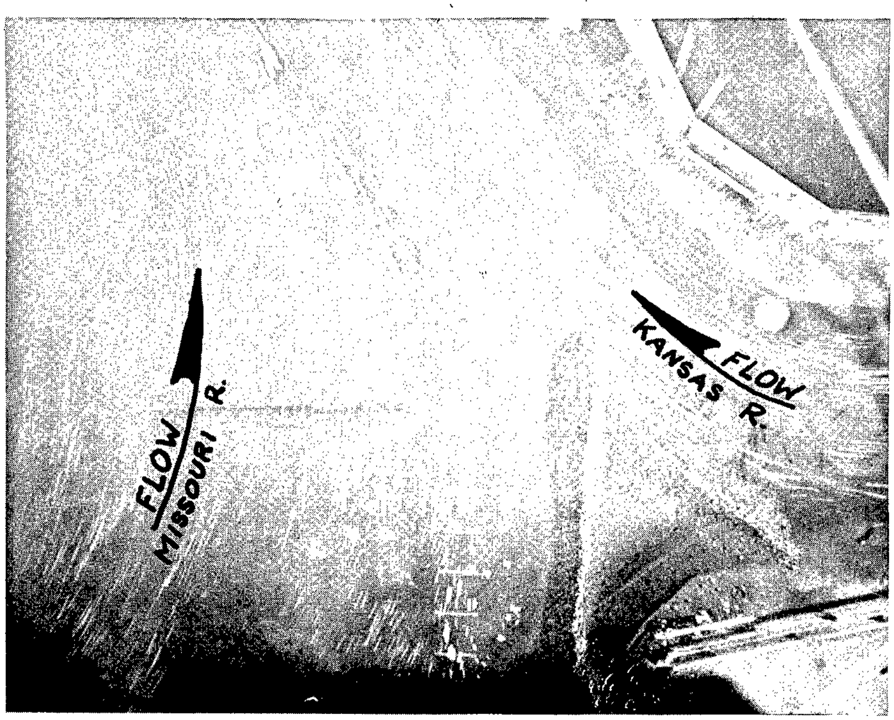


Figure 13. Photograph of structure tested at the confluence and resulting surface currents. Test 300D(L_2).

TABLE IV

MODEL WATER SURFACE ELEVATIONS
FOR
REDUCTION OF JUNCTION LOSS TESTS

Test Number	Structure Length	Structure Elevation	Water Surface Elevation Missouri	Water Surface Elevation Kansas
112D	---	---	0.705	0.695
$B(L_1)$	2.0	0.34	0.709	0.697
$B(L_2)$	3.6	0.34	0.706	0.699
$B(L_3)$	4.8	0.34	0.706	0.699
$C(L_1)$	2.0	0.52	0.706	0.698
$C(L_2)$	3.6	0.52	0.701	0.698
$C(L_3)$	4.8	0.52	0.704	0.702
$D(L_1)$	2.0	0.70	0.696	0.699
$D(L_2)$	3.6	0.70	0.686	0.708
$D(L_3)$	4.8	0.70	0.680	0.749

NOTES: 1. Flows for all tests were Q_M = 3.08 and Q_K = 3.18 cfs.

2. See Figure 13 for location of test structure.

ANALYSIS OF MODEL RESULTS

23. The water surface profiles shown on Plates 8 and 9 illustrate the presence and magnitude of the junction loss. The magnitude of this loss can be seen by comparing the water surface elevations at the confluence for various portions of flow, with that observed when 100% of the flow was present in the Missouri River (Q_M = 100%). These elevation differences are presented on Plate 10 as the junction loss versus percent of flow contributed by the Kansas River. These curves generally indicate that the maximum loss occurs when 50% of the total flow is contributed by each river. One exception to this can be noted; when a flow of 3.08 cfs was tested, a negative loss resulted. This is inconsistent with the other model results, and no apparent explanation exists for this inconsistency. The magnitude of the junction loss can also be noted on Plate 10 by comparing the difference in model rating curves at the confluence for the 50% and 100% Missouri River flow conditions.

24. The loss versus percent of Kansas River flow curves indicate that greater losses were experienced using the 1968 channel than when using the 1951 channel. This condition prevailed largely because of the method of defining the junction loss for the model. It was generally assumed that no loss existed when all flow was contributed by the Missouri River. However, during the 1951 flood, a large shoal developed below the confluence on the right bank as shown on Figure 3. In the model, this shoal retarded the Missouri River flows and resulted in slightly increased base water surface elevation. This increase caused minor losses of about two or three-thousandths of a foot in the model (approximately 0.2 prototype feet).

25. Analysis of the data in Table IV indicates that a structure located at the confluence (see Figure 13) would not significantly reduce the junction loss. These tests indicate that in order to decrease the loss, the angle at which the two flows merge should be reduced. To accomplish this, it was found that the structure must be large enough to actually retard the Kansas River flow, which in turn resulted in higher Kansas River backwater profiles.

26. Additional model loss evaluations were accomplished by computational procedures similar to the methods employed when estimating the prototype junction loss. The momentum equation defined by Chow[5] with the necessary assumptions to adapt it to the conditions of this confluence was used in this evaluation. The momentum coefficients presented in Table 3 were used to correct for uneven velocity distribution. The variation in the distribution of velocities across the channel width at the six model locations where observations were made are presented on

Plate 11. This computational analysis showed that the computed losses were comparable to the measured values; however, the results of these calculations are not considered conclusive because they were influenced by the assumptions that were made.

CONCLUSIONS

27. The investigation revealed the following:

a. The magnitude of the junction loss at the confluence of the Kansas and Missouri Rivers is proportioned to the total discharge of the two rivers and is not significantly influenced by the proportion from the respective rivers. As the amount of the flow increases, the junction loss increases.

b. A junction loss of 0.015 feet (1.0 feet in prototype), was observed when a prototype flow of 610,000 cfs was studied in the flume. This compares with an estimated value of 1.9 feet in the project Design Memorandum(6).

c. The dissipated internal energy does not appear to be a function of channel geometry. After the model channel was reshaped from 1951 to 1968 conditions, the water surface profiles in the vicinity of the confluence were changed as a result of bed elevation changes, but the observed losses remained nearly constant.

d. Placement of a structure at the confluence of the two streams does not improve the design flow profile. The tests revealed that in order to significantly change the direction of the Kansas River flow, the dike must be large enough to retard the Kansas River flows, which results in even higher Kansas River profiles.

28. The results of the model study are considered to be highly reliable. Many of the model tests were repeated to determine both the ability of the model to reproduce itself and the accuracy of the instrumentation. Only very minor differences were noted in these comparisons.

TABLE V

TABULATION OF MODEL TESTS

Test Number	Number of Tests	Channel Geometry	Discharge in C.F.S. Missouri River	Kansas River	Kansas R. Overflow	Prototype Flow Represented	Purpose of Test
1A-5E	26	1951	Variable	Variable	-		Establish accuracy of instrumentation
6A-6S	22	1951	0.646	4.207	1.026	573,000	Model verification
7A	1	1951	6.26	-	-	610,000	To establish the magnitude of model junction losses for various flow combinations representing a discharge of 610,000.
7B	1	1951	3.13	3.13	-		
7C	2	1951	2.26	4.00	-		
7D	1	1951	4.00	2.26	-		
7E	1	1951	-	6.26	-		
7F	1	1951	2.26	3.00	1.00		
8A	1	1951	5.13	-	-	500,000	To establish the magnitude of model junction losses for various flow combinations representing a discharge of 500,000.
8B	1	1951	2.57	2.57	-		
8C	1	1951	-	5.13	-		
8D	1	1951	1.85	3.28	-		
9A	2	1951	4.10	-	-	400,000	To establish the magnitude of model junction losses for various flow combinations representing a discharge of 400,000.
9B	1	1951	2.05	2.05	-		
9C	1	1951	-	4.10	-		
9D	1	1951	1.48	2.62	-		
10A	3	1951	3.08	-	-	300,000	To establish the magnitude of model junction losses for various flow combinations representing a discharge of 300,000.
10B	1	1951	1.54	1.54	-		
10C	1	1951	-	3.08	-		
10D	1	1951	1.11	1.97	-		
11A	1	1951	0.646	4.207	1.026	573,000	1951 flood flows.

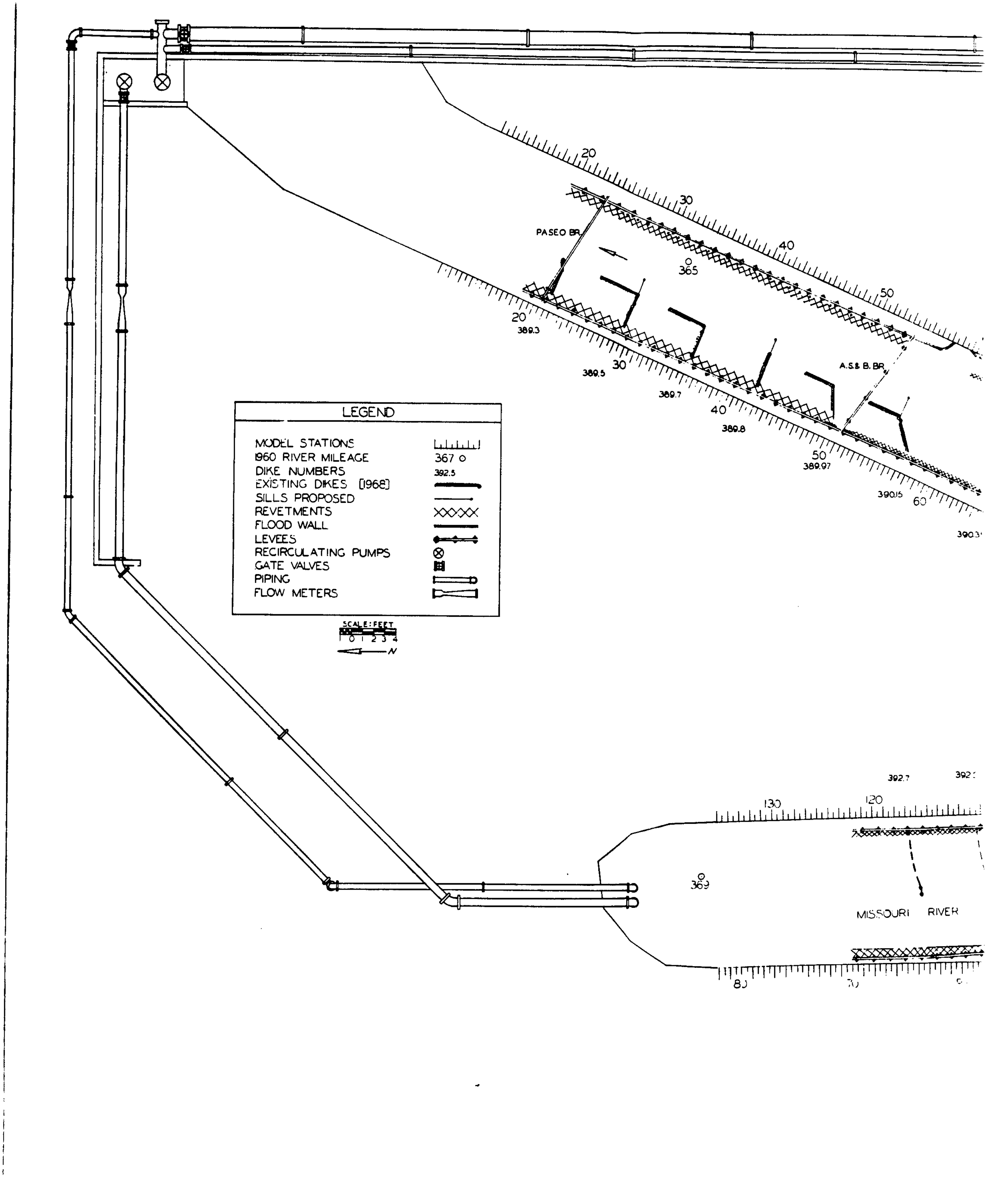
TABLE V (Cont'd)
TABULATION OF MODEL TESTS

Test Number	Number of Tests	Channel Geometry	Discharge in C.F.S. Missouri River	Kansas River	Kansas R. Overflow	Prototype Flow Represented	Purpose of Test
12A	1	1951	6.26	-	-	610,000	Series 12 same as series 7
12B	1	1951	5.13	1.13	-		
12C	1	1951	4.10	2.16	-		
12D	1	1951	3.08	3.18	-		
12E	1	1951	2.16	4.10	-		
12F	1	1951	1.13	5.13	-		
12G	1	1951	-	6.26	-		
56A	1	1968	0.626	4.207	1.026	573,000	1968 channel before
57A	1	1968	6.26	-	-		dikes 391.3, 391.5 & 391.95 placed in model.
106S	1	1968	0.646	4.207	1.026	573,000	1951 Flood Flows
107A	1	1968	6.26	-	-	610,000	
108A	1	1968	5.13	-	-	500,000	Discharges same as 8 series
108B	1	1968	2.57	2.57	-		(see note)
108C	1	1968	-	5.13	-		
108D	1	1968	1.85	3.28	-		
109A	1	1968	4.10	-	-	400,000	Discharge same as 9 series
109B	1	1968	2.05	2.05	-		(see note)
109C	1	1968	-	4.10	-		
109D	1	1968	1.48	2.62	-		
110A	1	1968	3.08	-	-	300,000	Discharge same as 10 series
110B	1	1968	1.54	1.54	-		(see note)
110C	1	1968	-	3.08	-		
110D	1	1968	1.11	1.97	-		

TABLE V (Cont'd)
TABULATION OF MODEL TESTS

Test Number	Number of Tests	Channel Geometry	Discharge in C.F.S. Missouri River	Kansas River	Kansas R. Overflow	Prototype Flow Represented	Purpose of Test
112A	2	1968	6.26	-	-	610,000	Discharge same as 12 series. (see note)
112B	1	1968	5.13	1.13	-		
112C	1	1968	4.10	2.16	-		
112D	2	1968	3.08	3.18	-		
112E	2	1968	2.16	4.10	-		
112F	1	1968	1.13	5.13	-		
112G	1	1968	-	6.26	-		
106W	1	1968	4.11	-	-	400,000	1952 Flood Flows
113A	1	1968	0.40	-	-	40,000	Normal Flows
212	4	1968	Variable	Variable	-		Photos taken of surface currents
300 Series	9	1968	3.08	3.18	-	610,000	See Table IV

NOTE: All 100 Series tests are repeats of previous tests. Example, Test 108A utilized same flows as test 8A. Channel geometry was changed from 1951 to 1968 conditions.


LEGEND
MODEL STATIONS
1960 RIVER MILEAGE
367
DIKE NUMBERS
392.5
EXISTING DIKES (1968)
SILLS PROPOSED
REVETMENTS
FLOOD WALL
LEVEES
RECIRCULATING PUMPS
GATE VALVES
PIPING
FLOW METERS
SCALE: FEET
0 1 2 3 4
N
PASEO BR.
A.S.& B. BR.
365
369
MISSOURI RIVER
389.3
389.5
389.7
389.8
389.97
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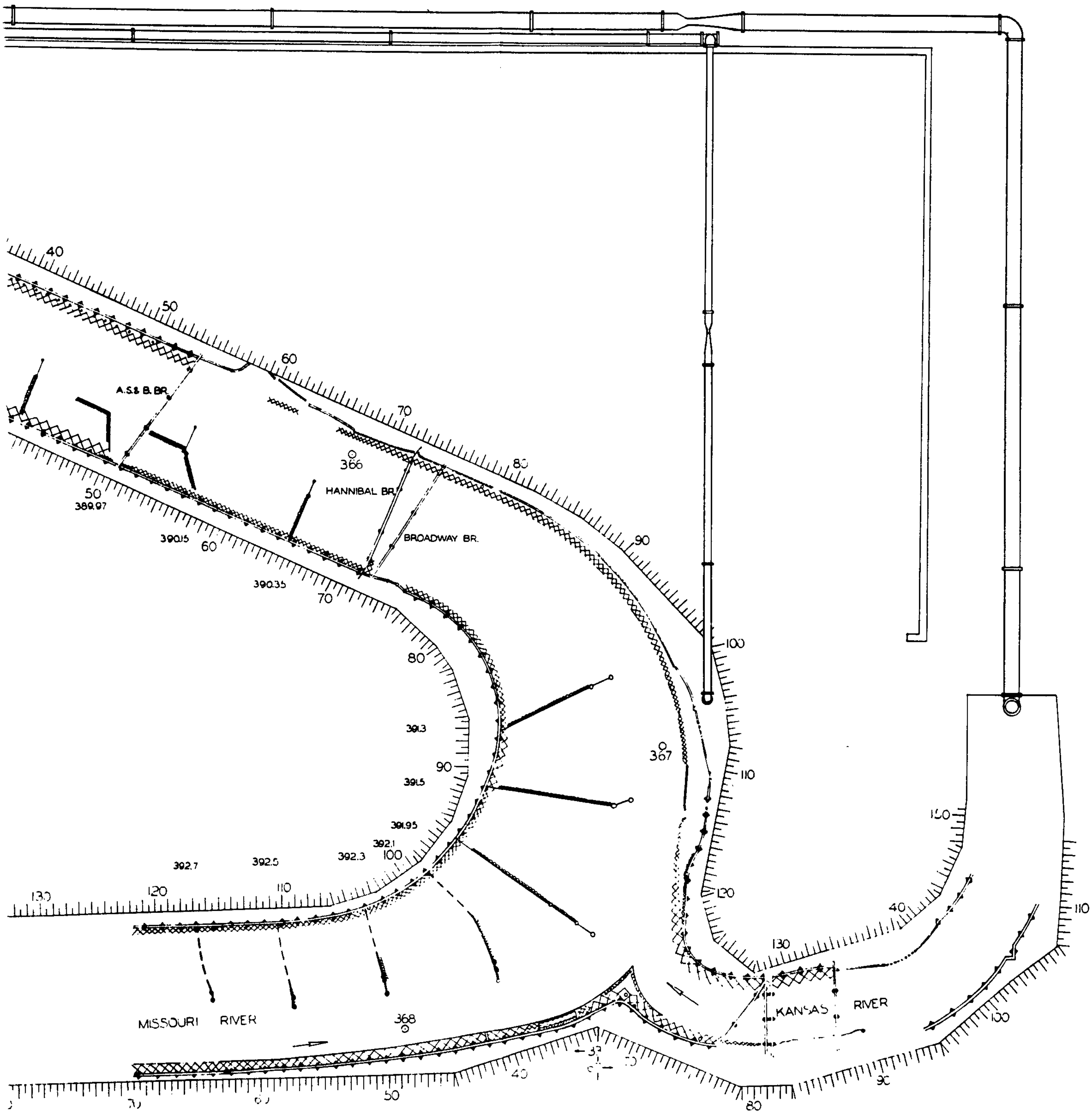
120
130

(1)



THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

MISSOURI RIVER DESIGN STUDY

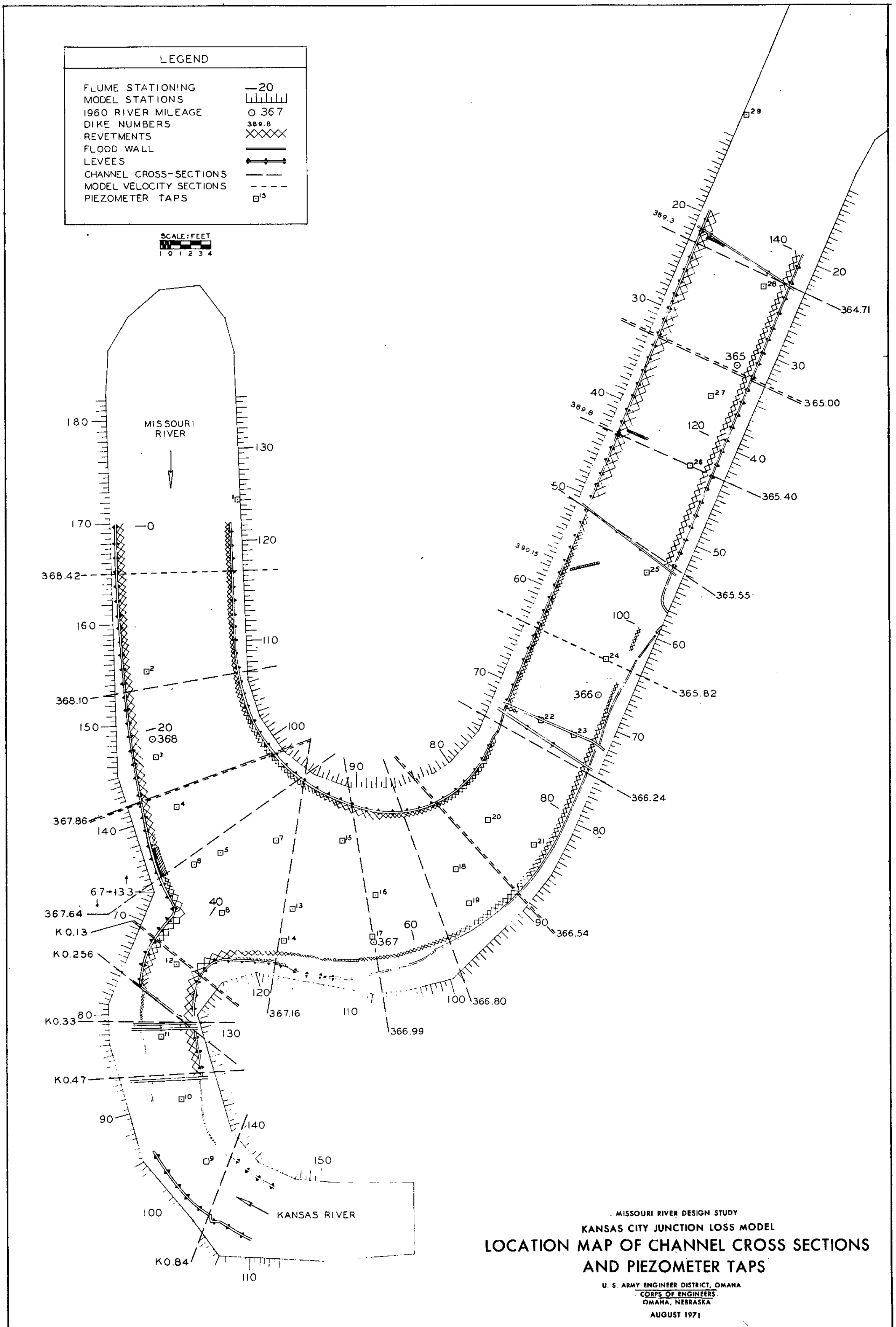
KANSAS CITY JUNCTION LOSS MODEL

BUILDING PLAN WITH MODEL LAYOUT

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

AUGUST 1971

PLATE 1



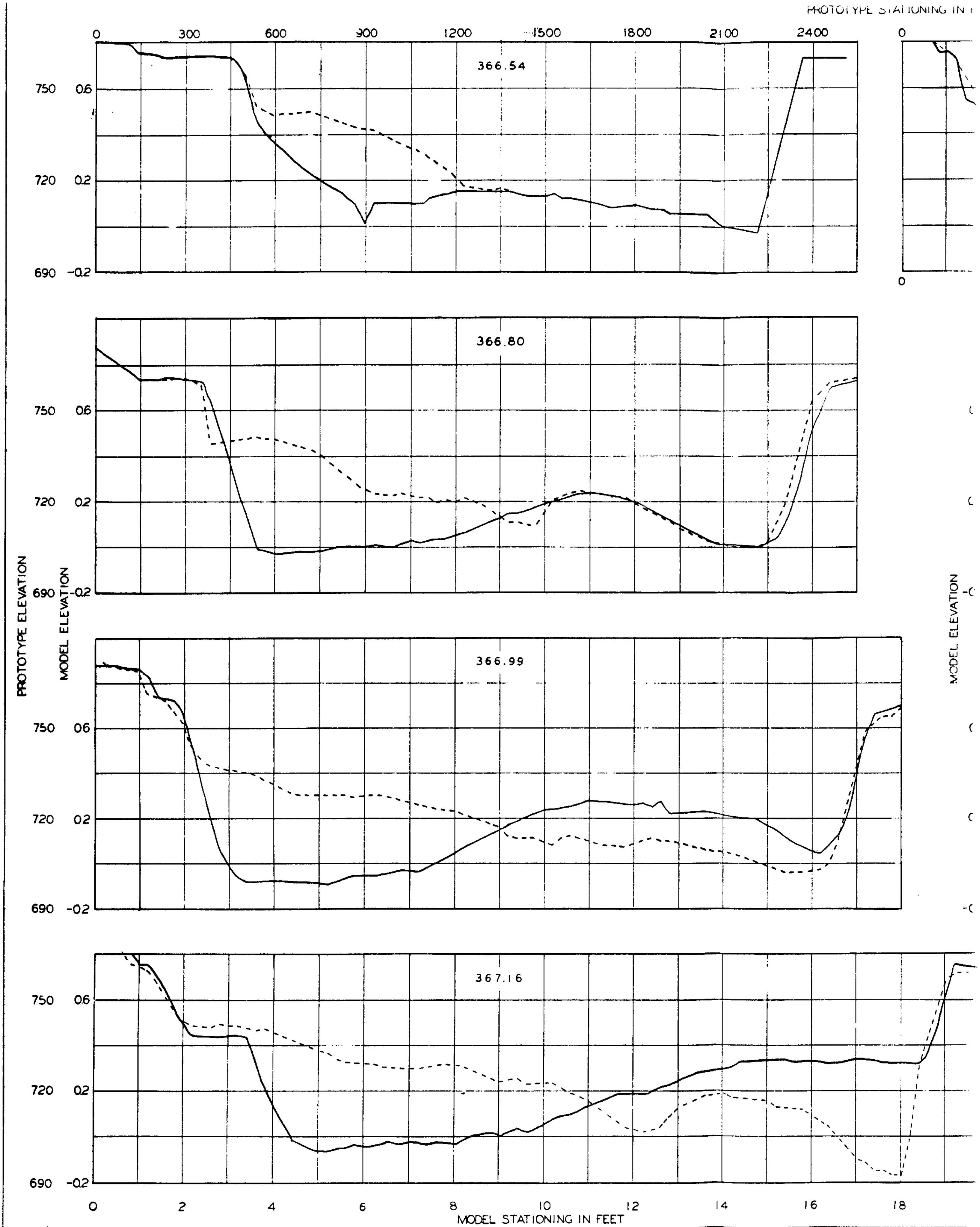
MISSOURI RIVER DESIGN STUDY

KANSAS CITY JUNCTION LOSS MODEL

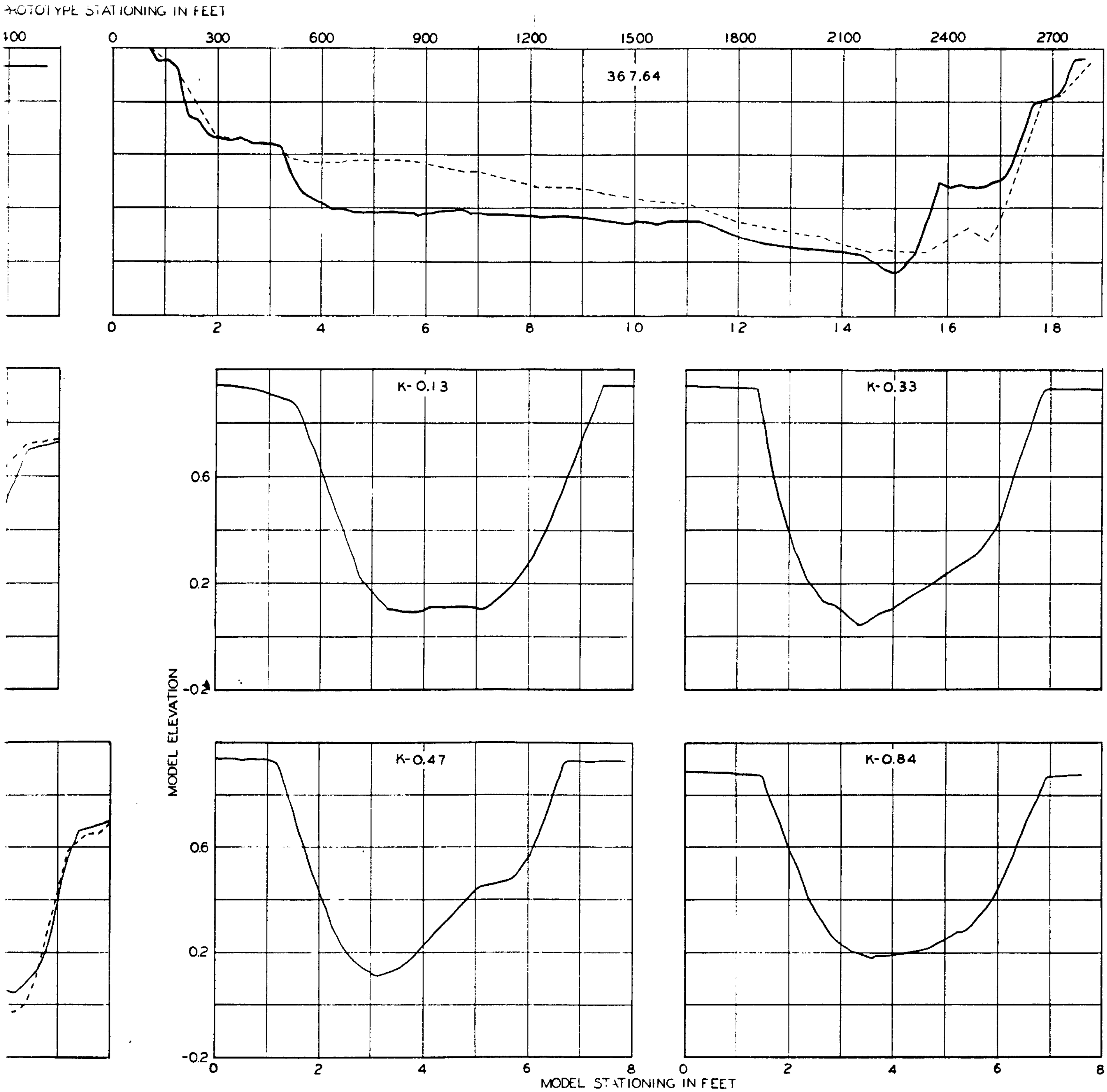
LOCATION MAP OF CHANNEL CROSS SECTIONS AND PIEZOMETER TAPS

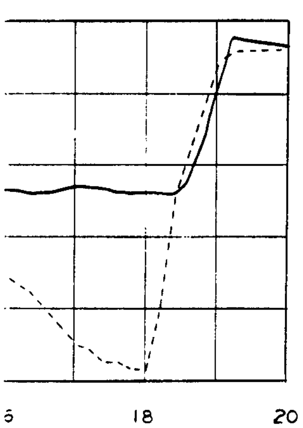
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
AUGUST 1971

PLATE NO. 2



PROTOTYPE STATIONING IN
0
300
600
900
1200
1500
1800
2100
2400
366.54
366.80
366.99
367.16
750
720
690
0.6
0.2
-0.2
PROTOTYPE ELEVATION
MODEL ELEVATION
0
2
4
6
8
10
12
14
16
18
MODEL STATIONING IN FEET





LEGEND	
366.80	SECTION NUMBER [1960 RIVER MILE]
K-0.13	SECTION NUMBER [KANSAS RIVER]
————	1951 CHANNEL
------	1968 CHANNEL

NOTE: ALL STATIONING LEFT TO RIGHT LOOKING DOWNSTREAM
SEE PLATE 2 FOR SECTION LOCATIONS

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

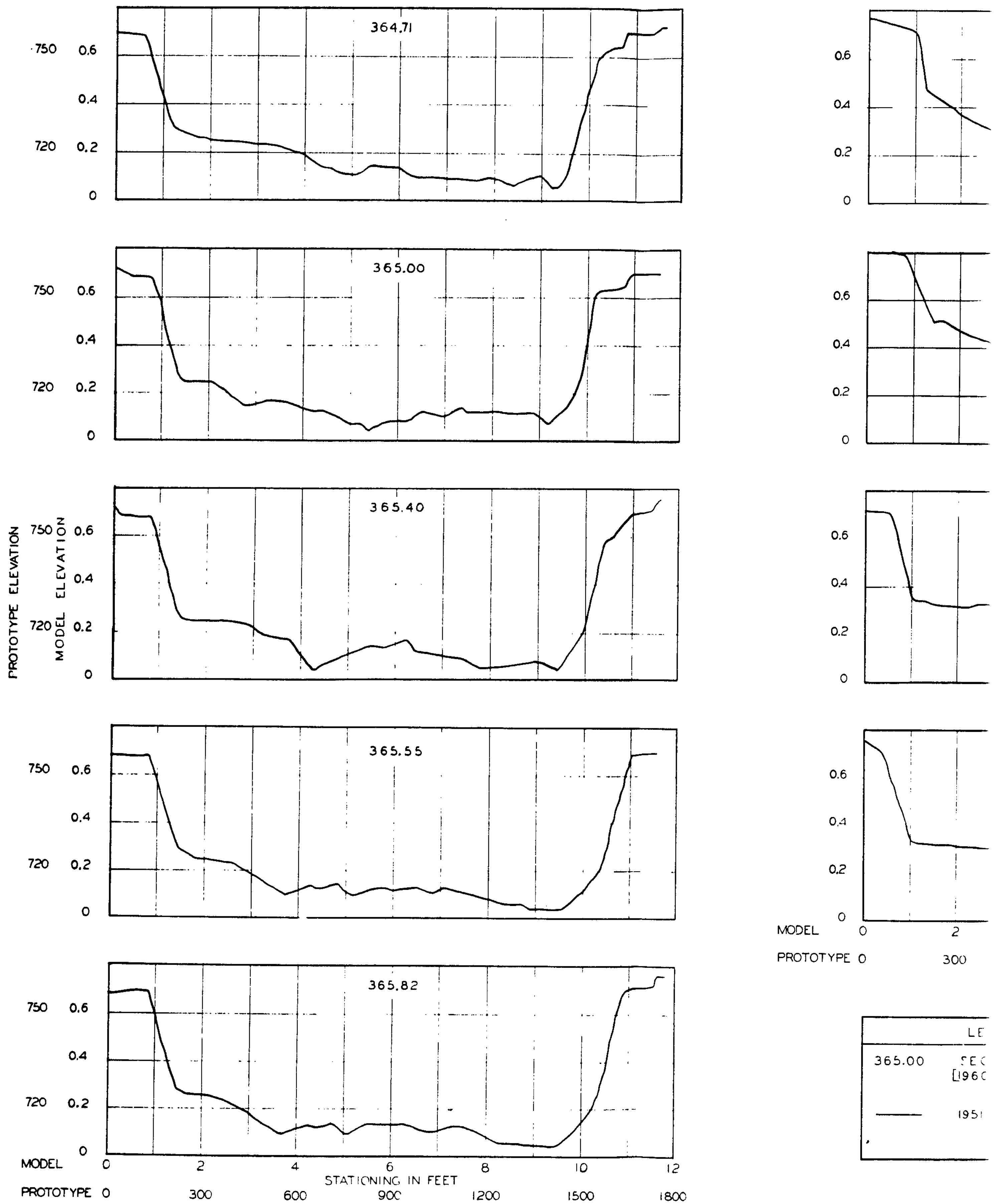
MISSOURI RIVER DESIGN STUDY
KANSAS CITY JUNCTION LOSS MODEL

MODEL CROSS SECTIONS

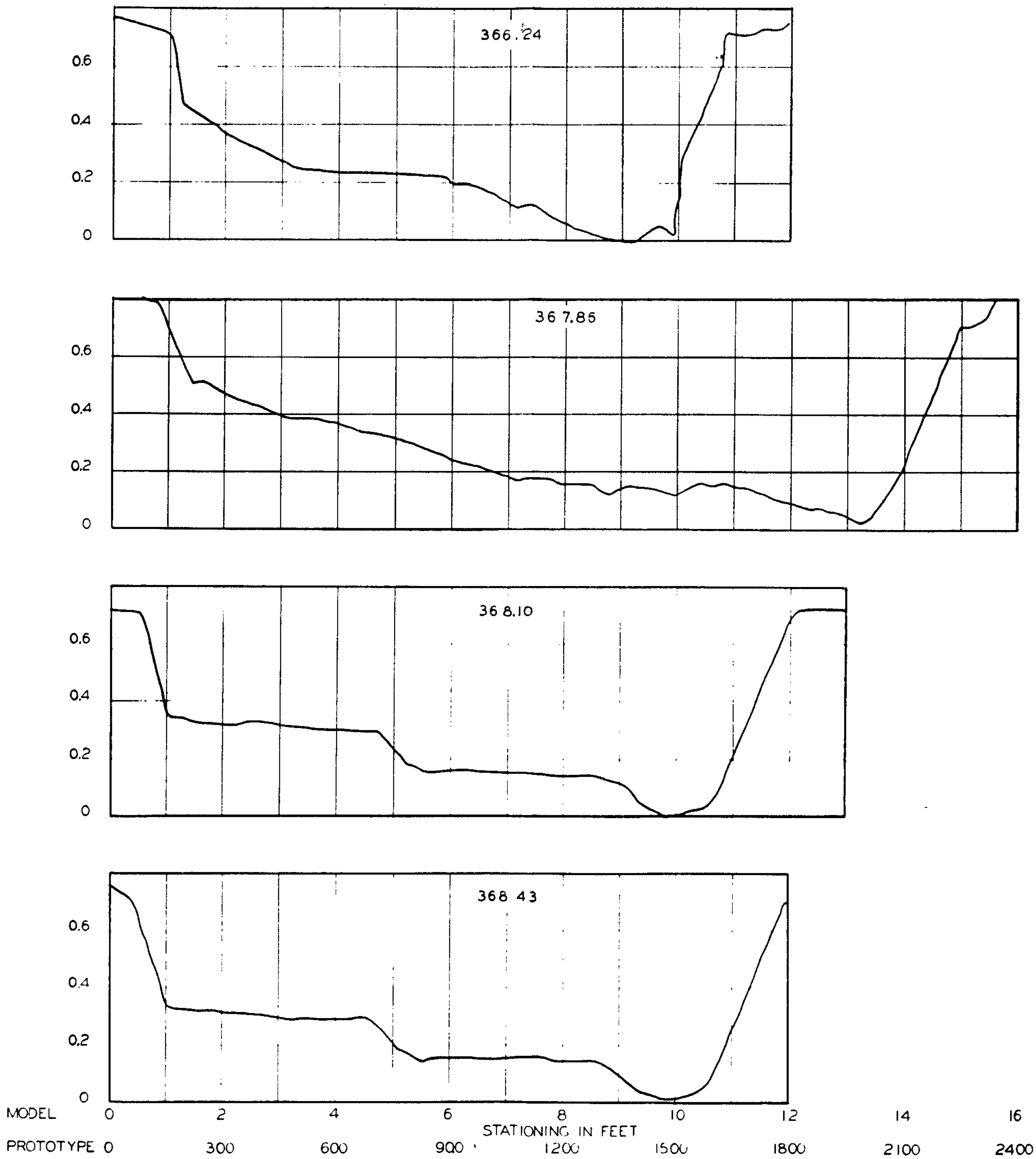
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
AUGUST 1971

PLATE NO. 3

2



364.71
365.00
365.40
365.55
365.82
PROTOTYPE ELEVATION
MODEL ELEVATION
750
720
0.6
0.4
0.2
0
MODEL 0 2 4 6 8 10 12
STATIONING IN FEET
PROTOTYPE 0 300 600 900 1200 1500 1800
LE
365.00
195



LEGEND	
365.00	SECTION NUMBER [1960 RIVER MILE]
———	1951 CHANNEL

NOTE: ALL STATIONING LEFT TO RIGHT LOOKING DOWNSTREAM
SEE PLATE 2 FOR SECTION LOCATIONS

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

MISSOURI RIVER DESIGN STUDY

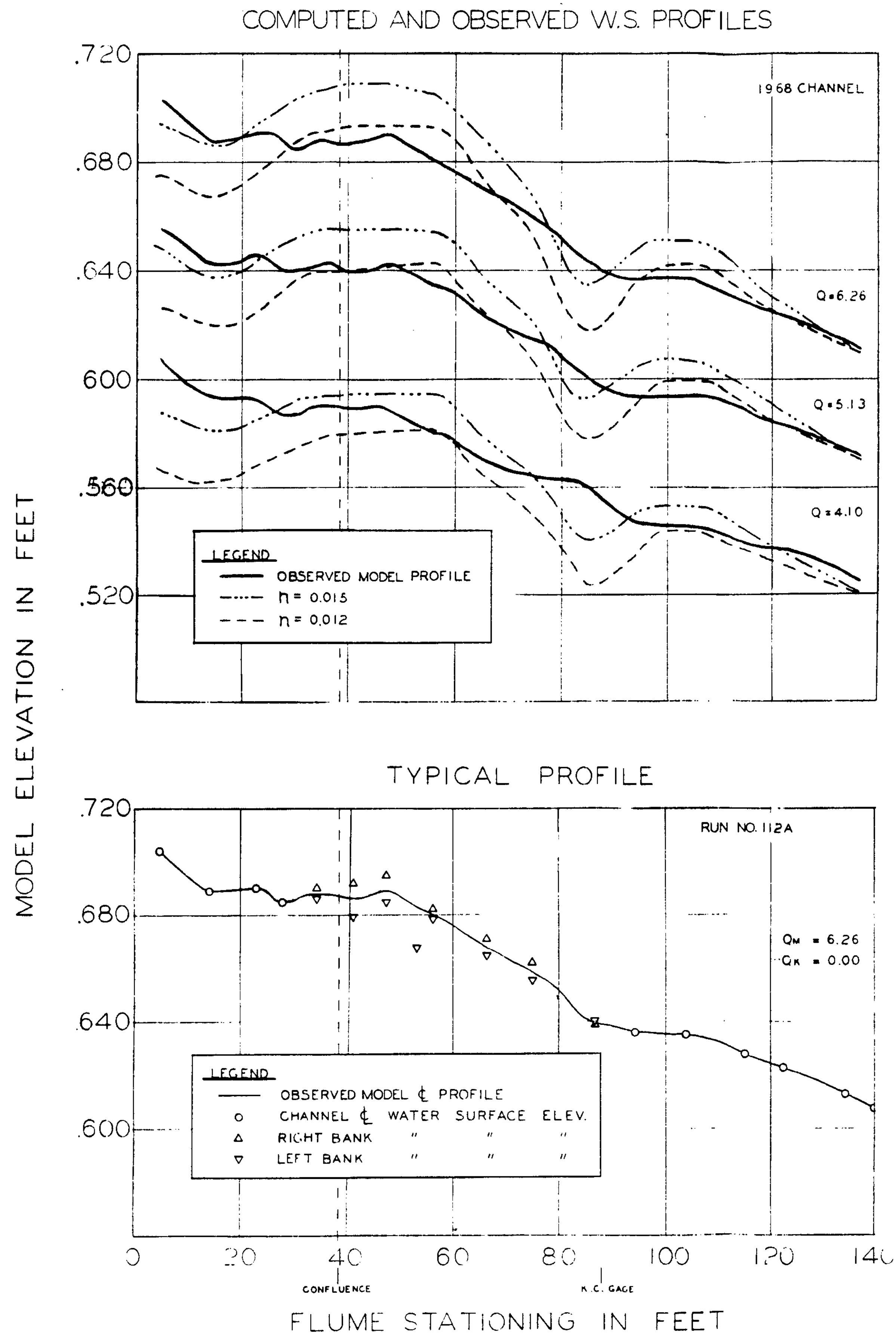
KANSAS CITY JUNCTION LOSS MODEL

MODEL CROSS SECTIONS

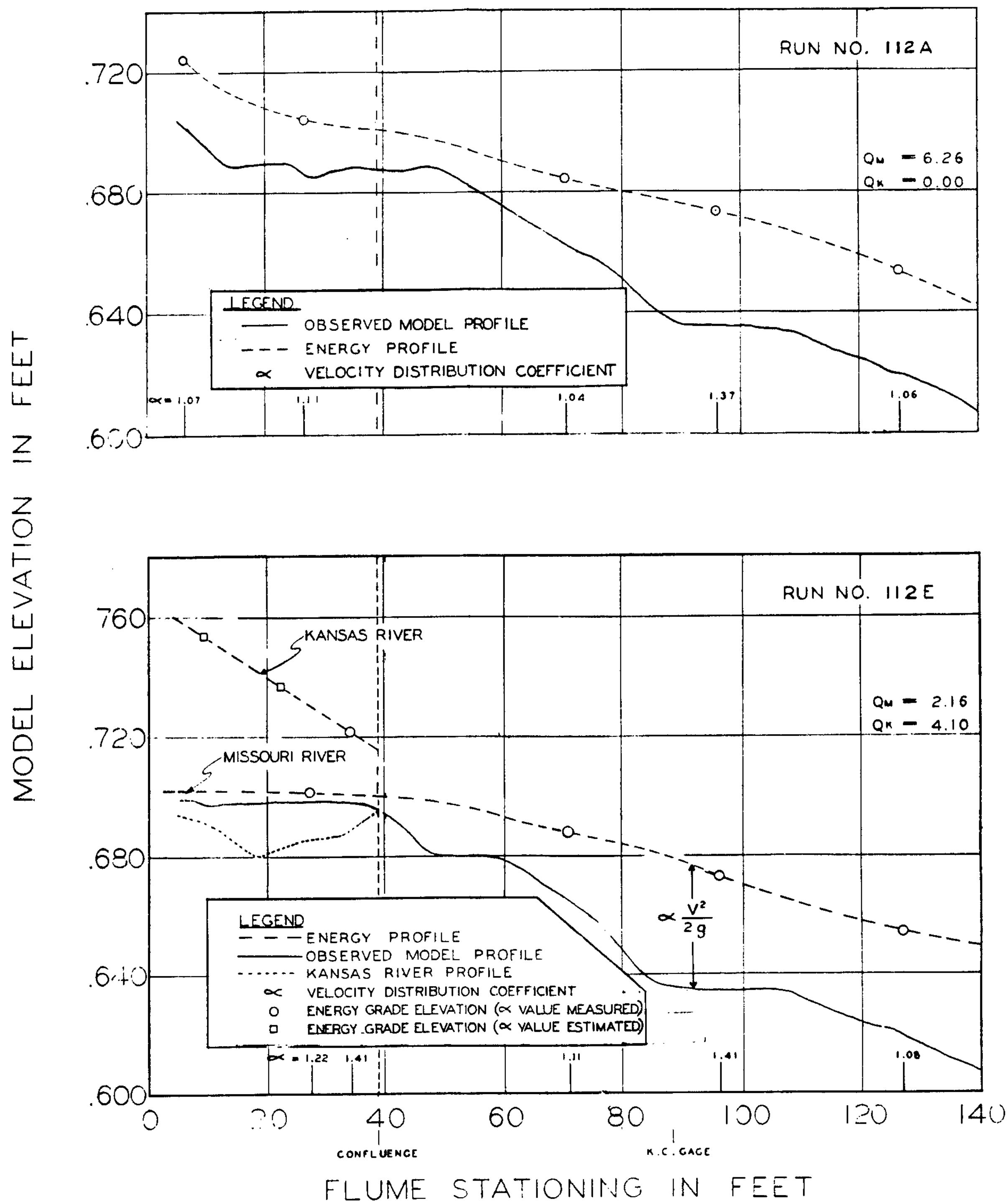
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
AUGUST 1971

PLATE NO. 4

2


COMPUTED AND OBSERVED W.S. PROFILES
1968 CHANNEL
Q=6.26
Q=5.13
Q=4.10
LEGEND
OBSERVED MODEL PROFILE
n = 0.015
n = 0.012
MODEL ELEVATION IN FEET
TYPICAL PROFILE
RUN NO. 112A
QM = 6.26
QK = 0.00
LEGEND
OBSERVED MODEL ℄ PROFILE
CHANNEL ℄ WATER SURFACE ELEV.
RIGHT BANK " " "
LEFT BANK " " "
CONFLUENCE
K.C. GAGE
FLUME STATIONING IN FEET

ENERGY PROFILES



THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

MISSOURI RIVER DESIGN STUDY

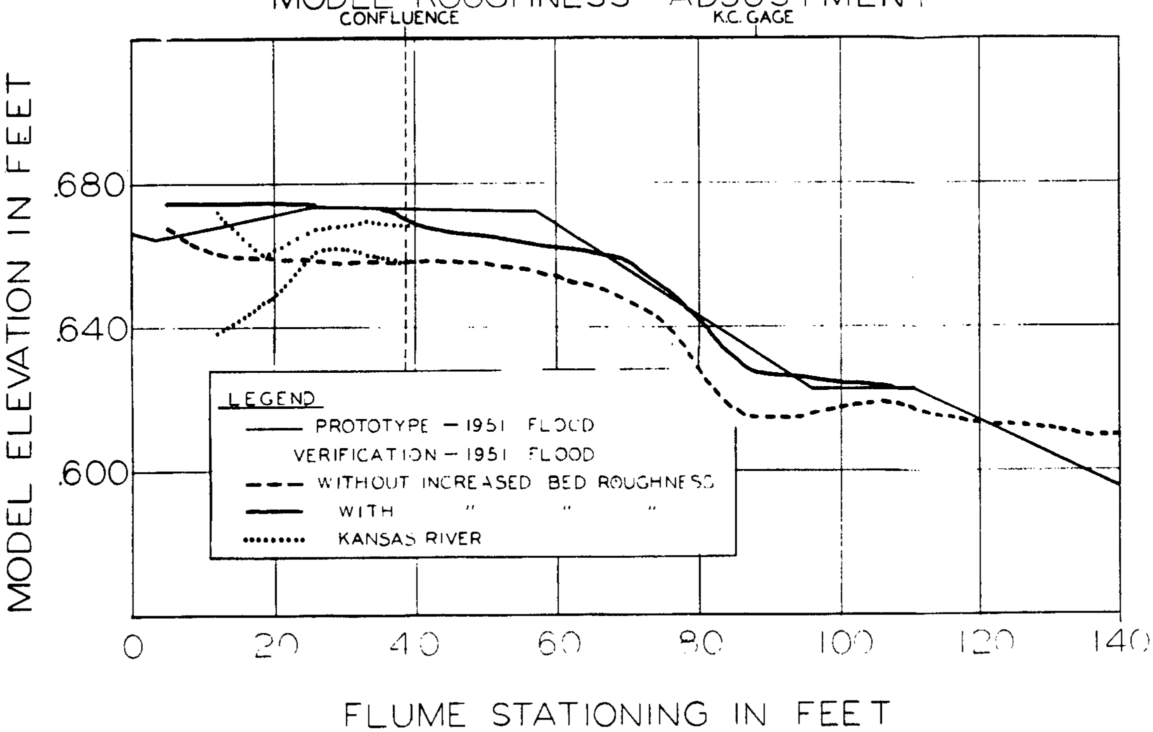
KANSAS CITY JUNCTION LOSS MODEL

SAMPLE WATER SURFACE AND ENERGY PROFILES

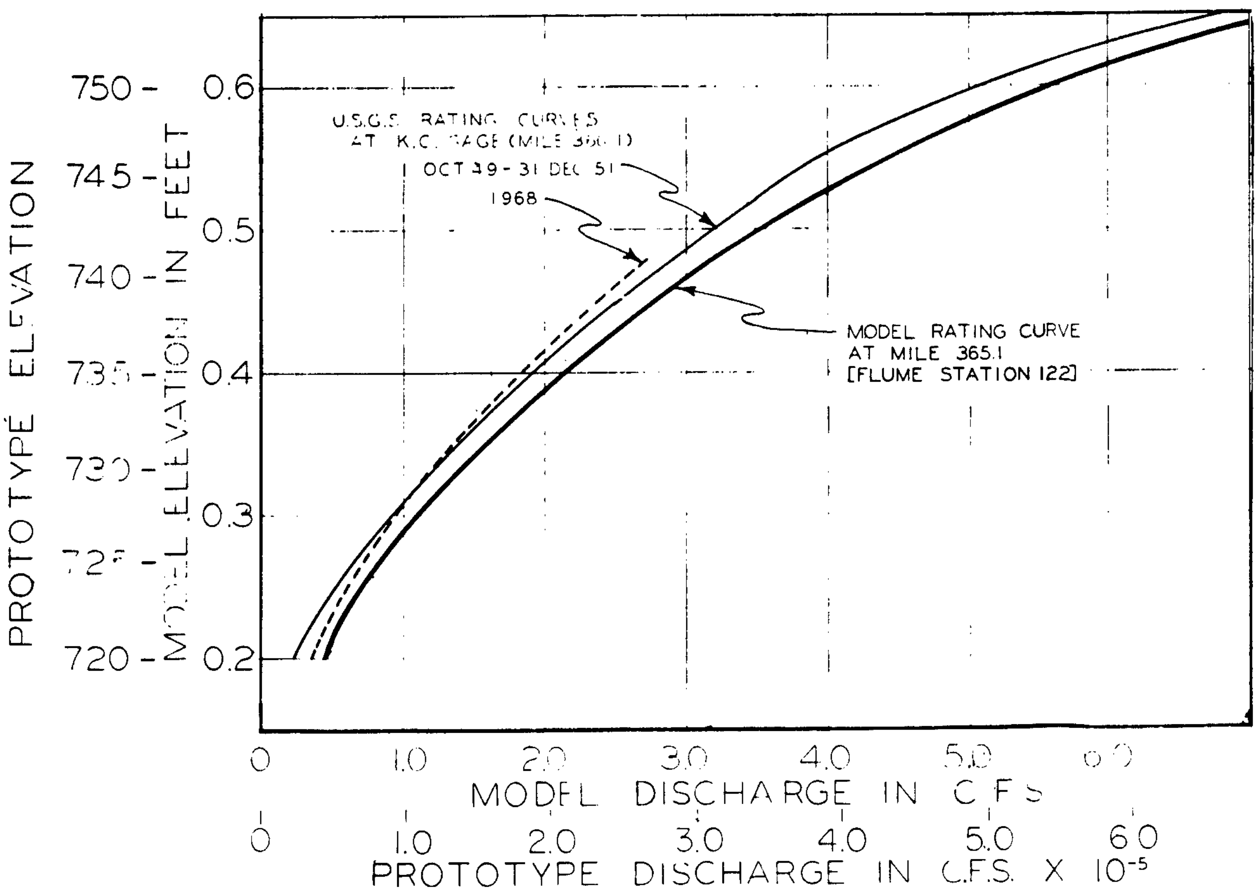
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
AUGUST 1971

WATER SURFACE PR

MODEL ROUGHNESS ADJUSTMENT

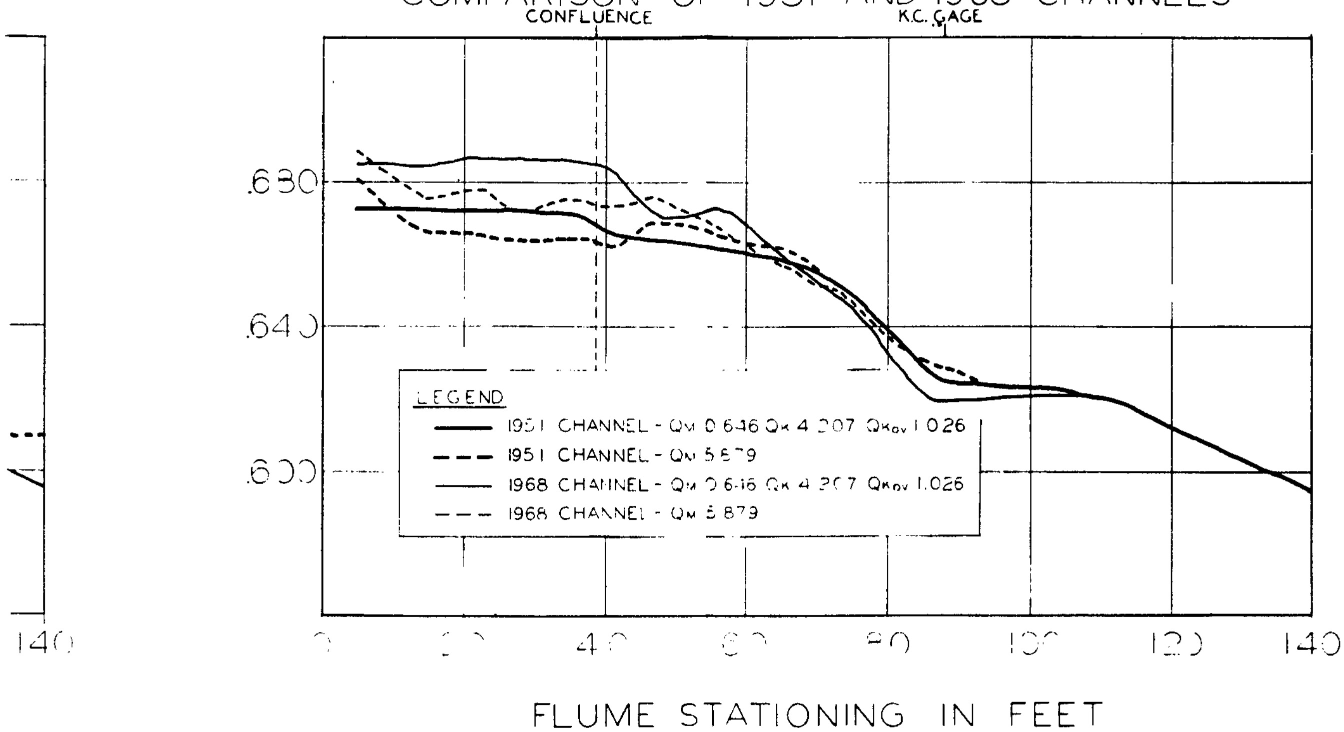


RATING CURVES



ER SURFACE PROFILES

COMPARISON OF 1951 AND 1968 CHANNELS



NOTES: Profiles presented in upper left graph were observed during model tests in which 1951 flood flows were represented. Dashed line indicates original test results and solid line shows closer reproduction of prototype profile after increasing the model roughness.

Solid line profiles in upper right graph were observed during model tests in which 1951 flood flows were represented. Dashed lines indicate profiles for comparable tests in which the total flow was contributed by the Missouri River. See page iii for description of symbols.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

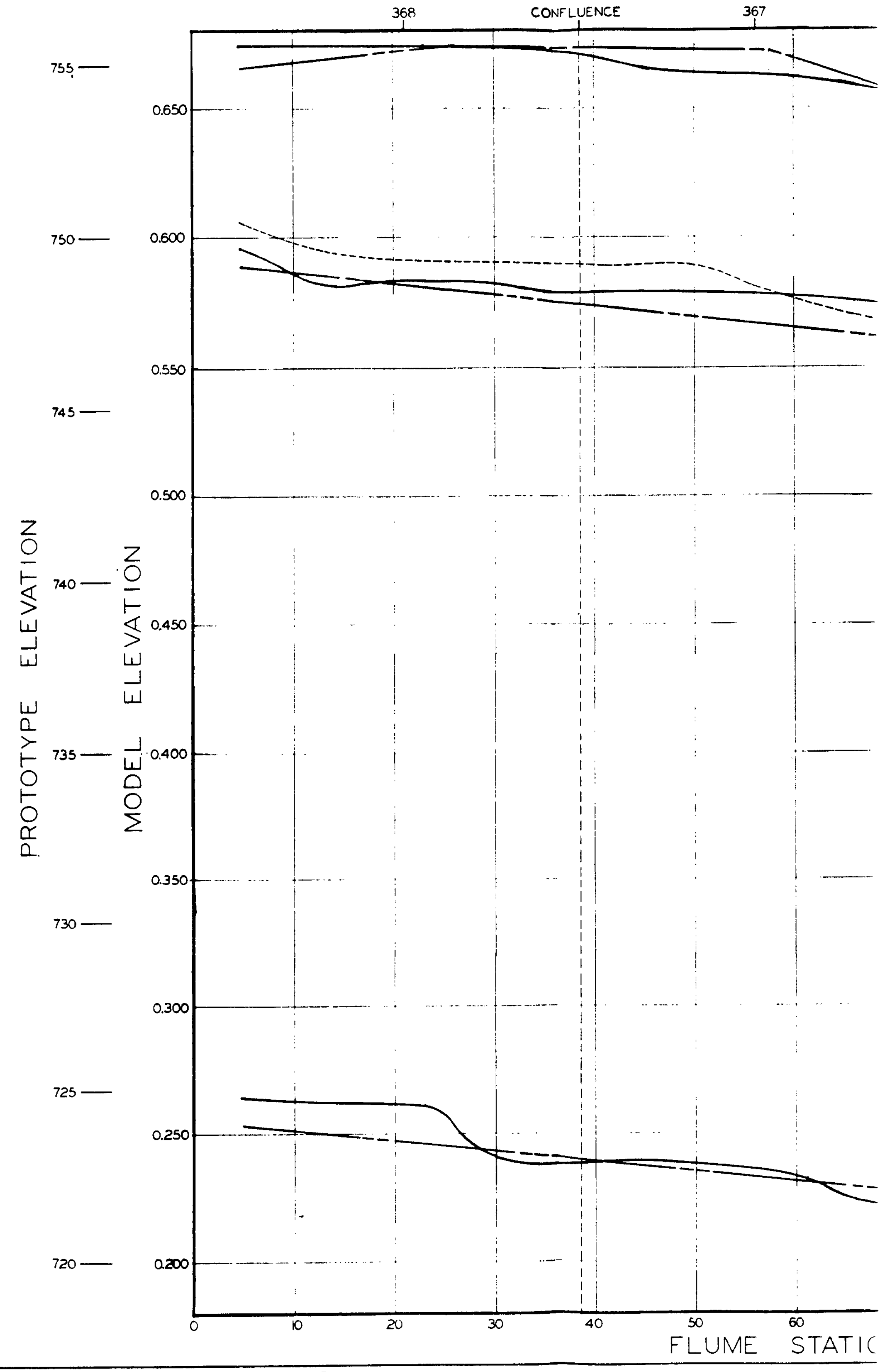
MISSOURI RIVER DESIGN STUDY

KANSAS CITY JUNCTION LOSS MODEL

WATER SURFACE PROFILES AND RATING CURVE FOR MODEL ROUGHNESS ADJUSTMENT

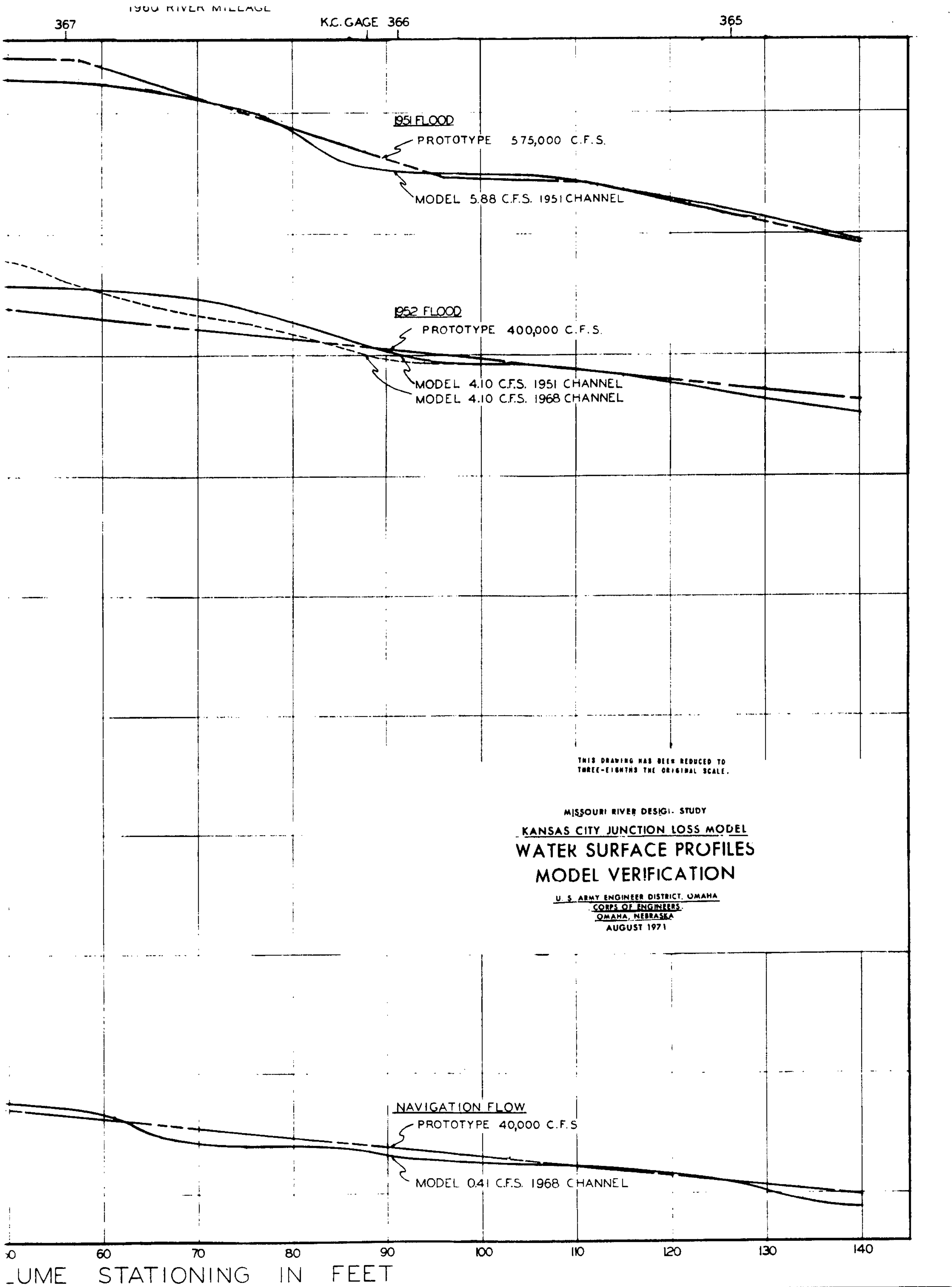
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
AUGUST 1971

PLATE NO. 6



368
CONFLUENCE
367
755
750
745
740
735
730
725
720
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
PROTOTYPE ELEVATION
MODEL ELEVATION
0
10
20
30
40
50
60
FLUME STATIC

①



THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

MISSOURI RIVER DESIGN STUDY

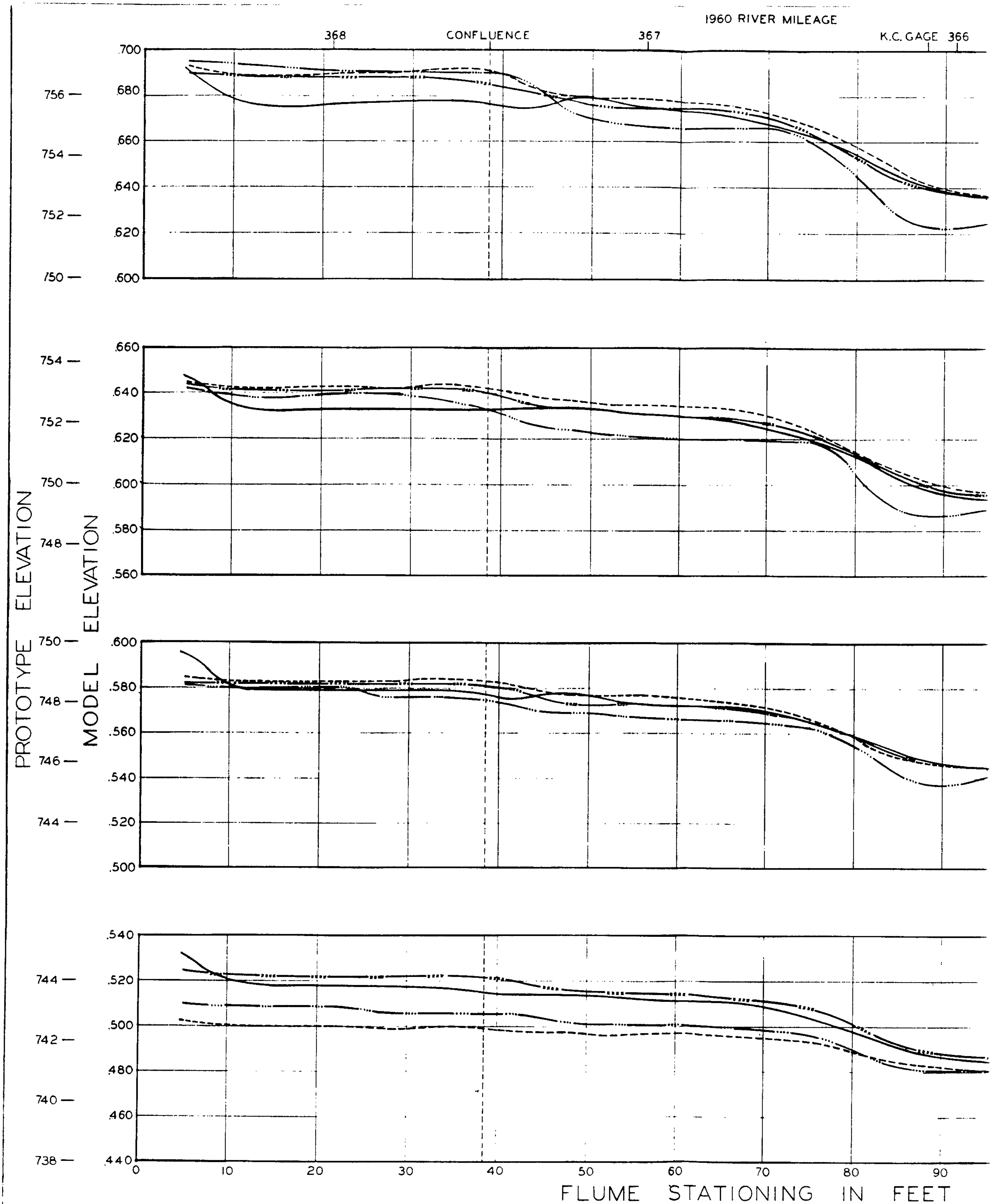
KANSAS CITY JUNCTION LOSS MODEL

WATER SURFACE PROFILES
MODEL VERIFICATION

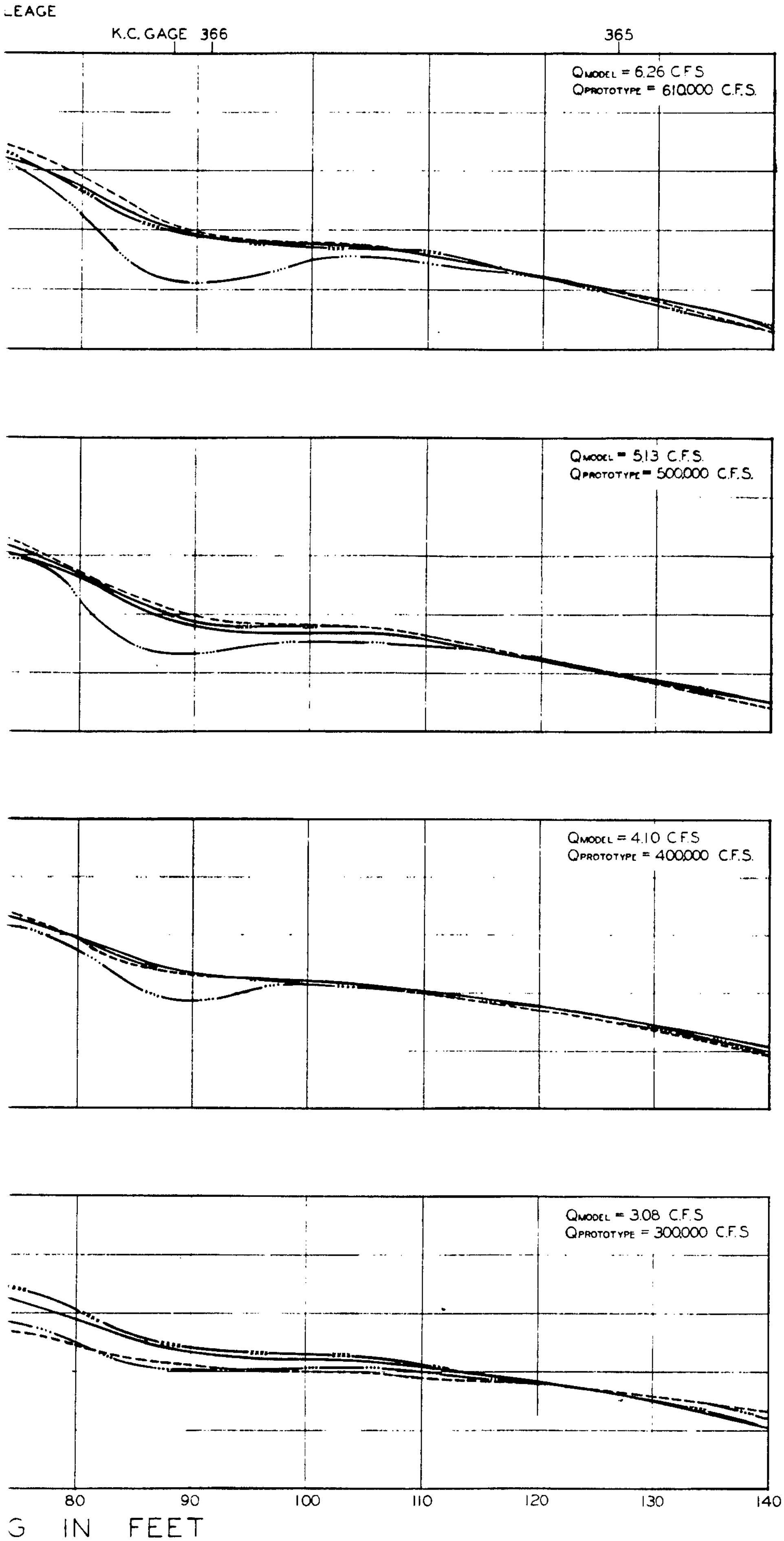
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
AUGUST 1971

PLATE NO. 7

2


1960 RIVER MILEAGE
368
CONFLUENCE
367
K.C. GAGE
366
PROTOTYPE ELEVATION
MODEL ELEVATION
FLUME STATIONING IN FEET

①



LEGEND

————	QM=100% QK= 0%
– – – – –	QM= 50% QK= 50%
——····——	QM= 34% QK= 66%
——····——	QM= 0% QK 100%

NOTE: The purpose of the tests from which these profiles were measured was to determine the model junction loss for various flow combinations and rates. The model channel was shaped to represent 51 flood conditions for all profiles presented on this plate.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

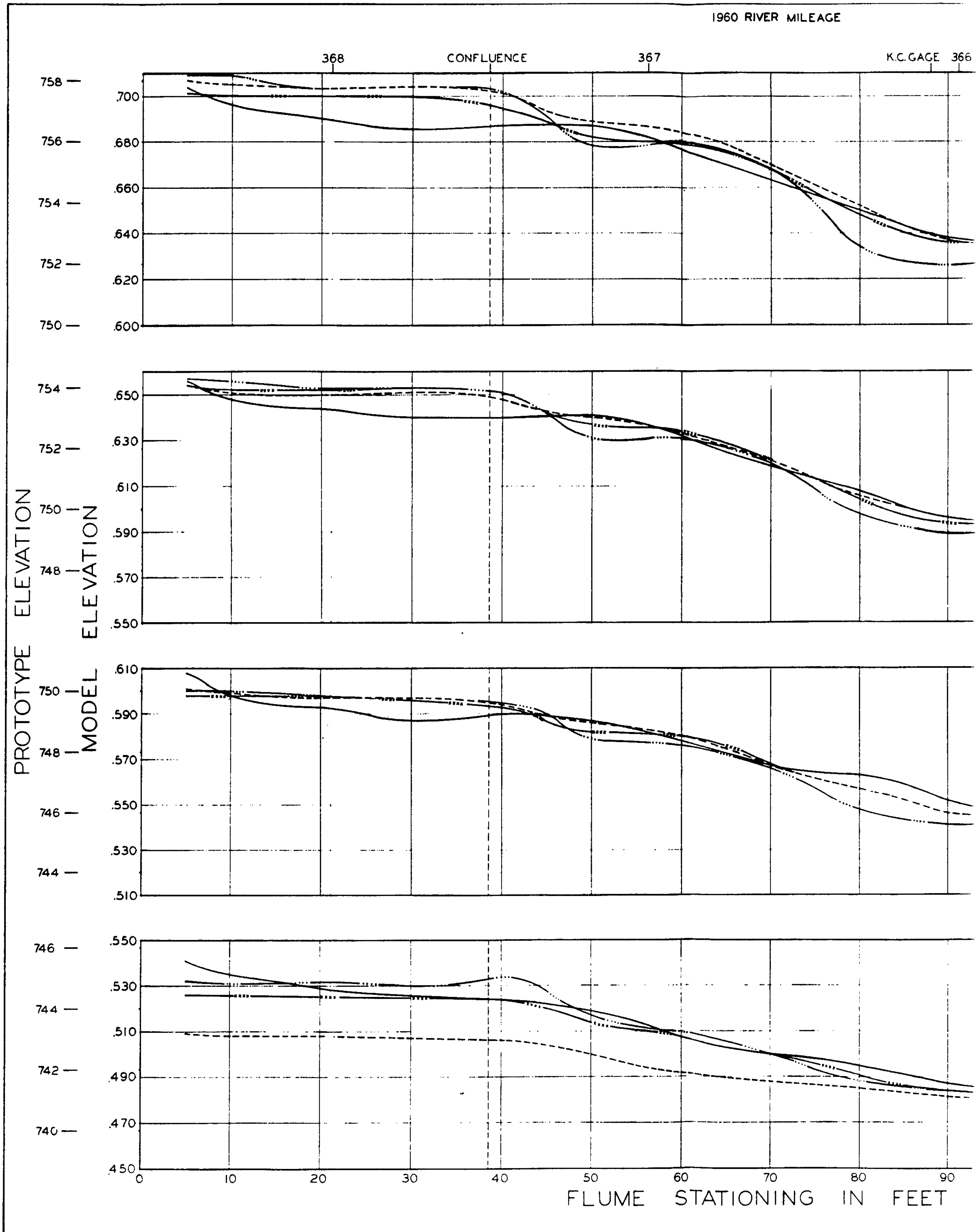
MISSOURI RIVER DESIGN STUDY

KANSAS CITY JUNCTION LOSS MODEL

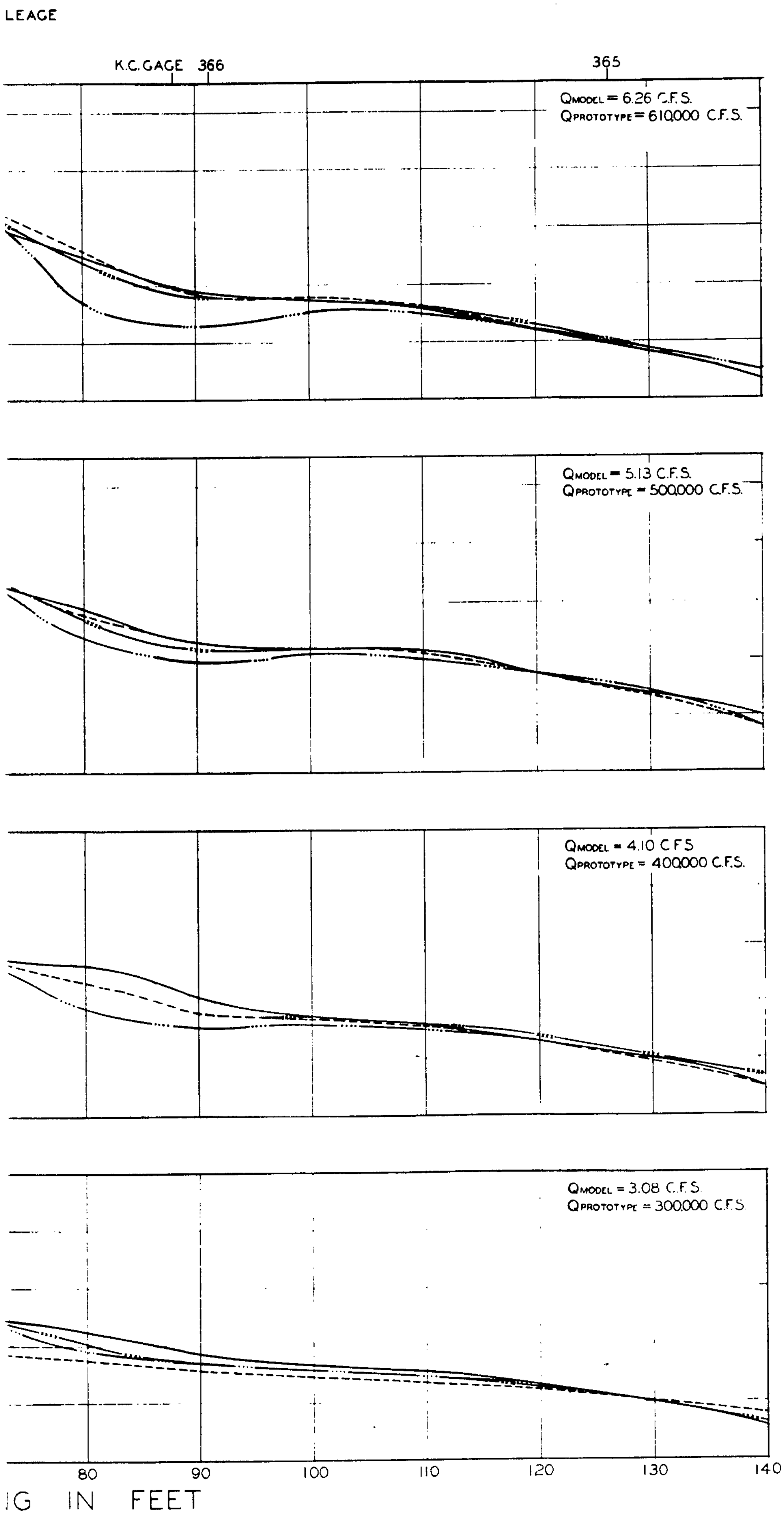
WATER SURFACE PROFILES 1951 CHANNEL

U. S. ARMY ENGINEER DISTRICT, OMAHA.
CORPS OF ENGINEERS.
OMAHA, NEBRASKA
AUGUST 1971

PLATE NO. 8


1960 RIVER MILEAGE
368
CONFLUENCE
367
K.C. GAGE
366
PROTOTYPE ELEVATION
MODEL ELEVATION
FLUME STATIONING IN FEET

1



LEGEND

————	QM = 100%	QK = 0%
- - - - - -	QM = 50%	QK = 50%
——xxxx——	QM = 34%	QK = 66%
——····——	QM = 0%	QK = 100%

NOTE: These profiles represent the same flows as those presented on plate 8. The channel geometry near the confluence was reshaped from '51 flood conditions to 1968 conditions.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

MISSOURI RIVER DESIGN STUDY

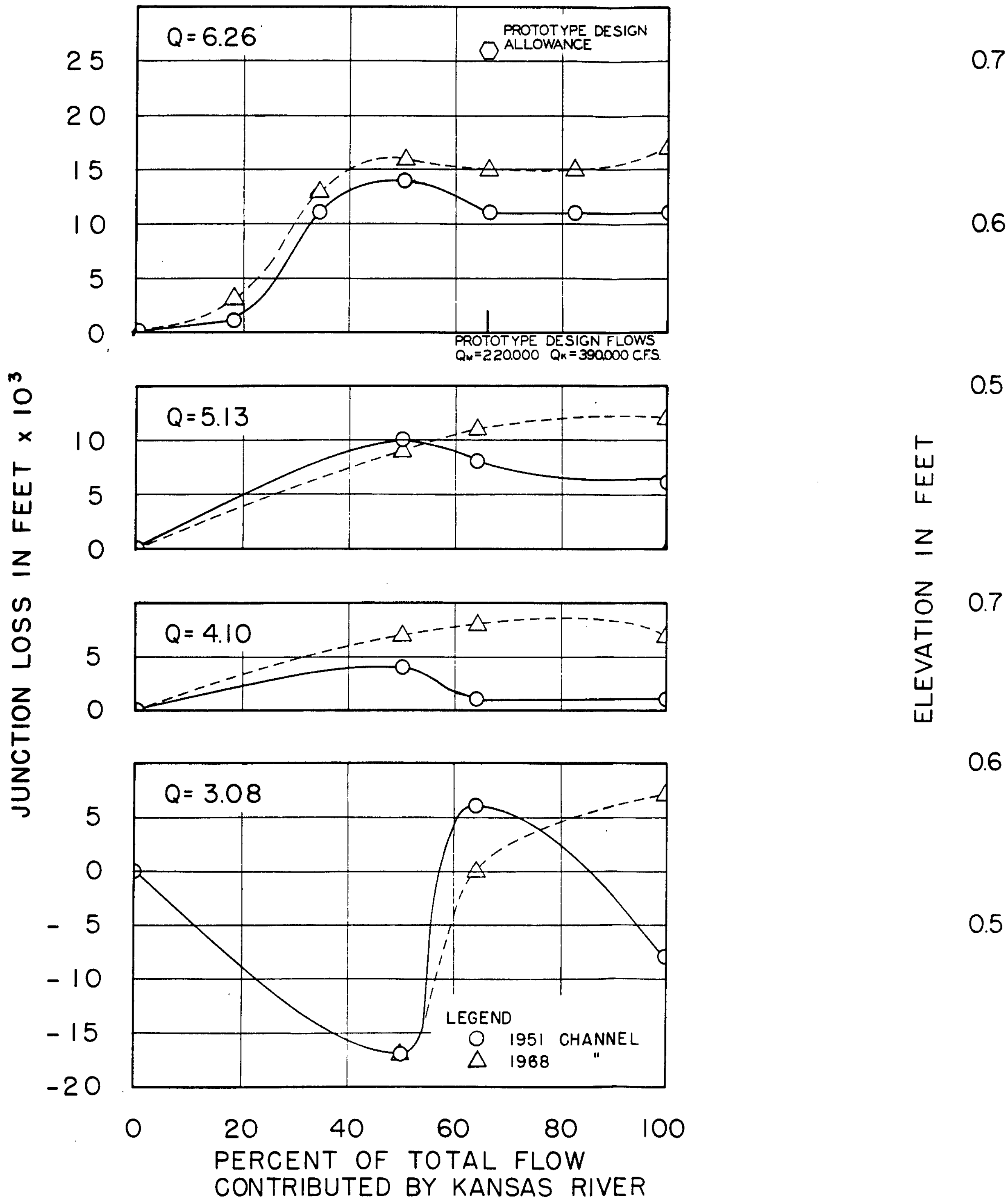
KANSAS CITY JUNCTION LOSS MODEL

WATER SURFACE PROFILES
1968 CHANNEL

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
AUGUST 1971

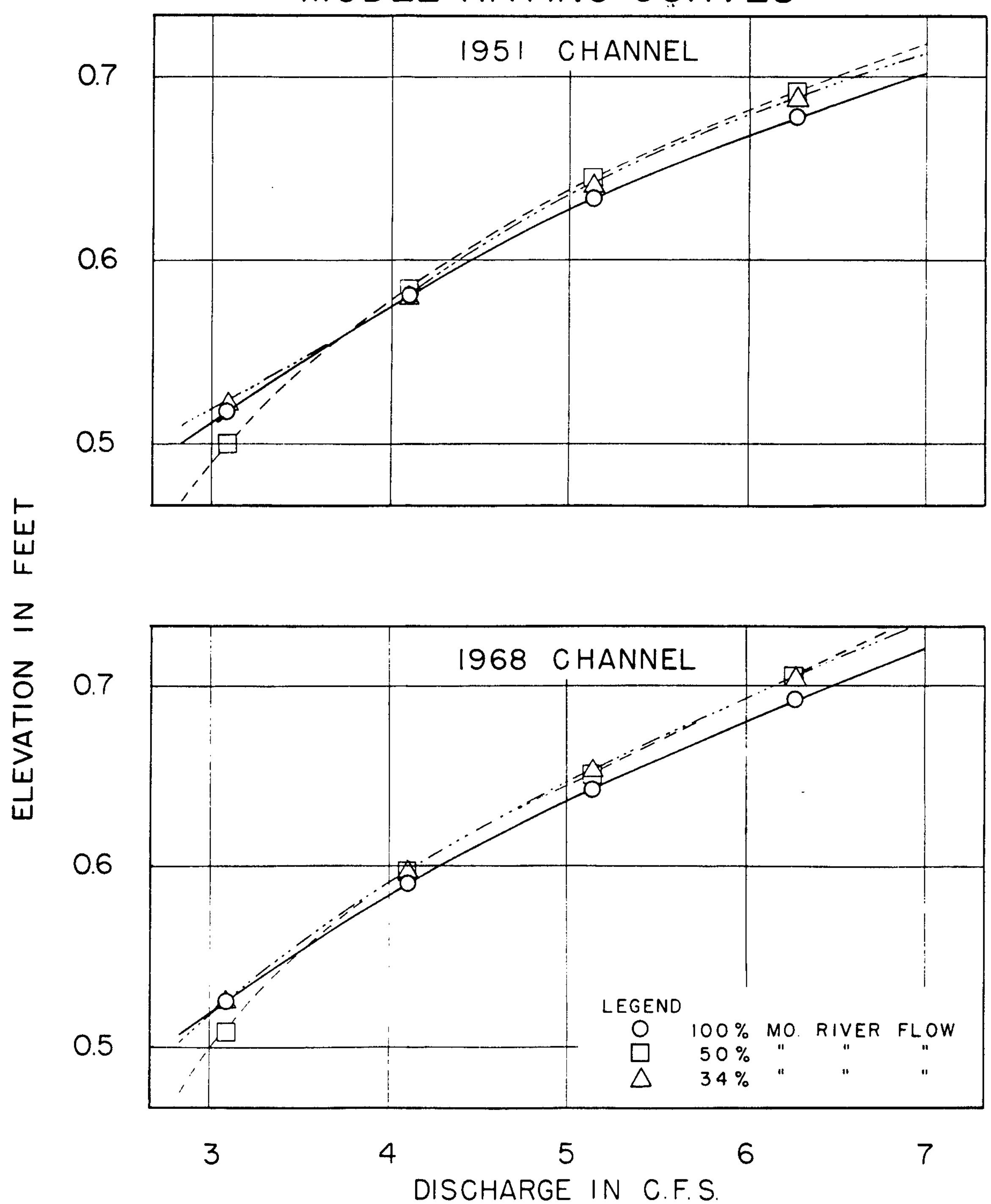
PLATE NO. 9

MODEL JUNCTION LOSS



NOTES: 1. ALL VALUES ARE FOR MISSOURI RIVER AT THE CONFLUENCE
2. ALL VALUES DERIVED FROM MODEL OBSERVATIONS UNLESS OTHERWISE STATED

MODEL RATING CURVES



THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

JES ARE FOR MISSOURI RIVER
CONFLUENCE
JES DERIVED FROM MODEL
IONS UNLESS OTHERWISE

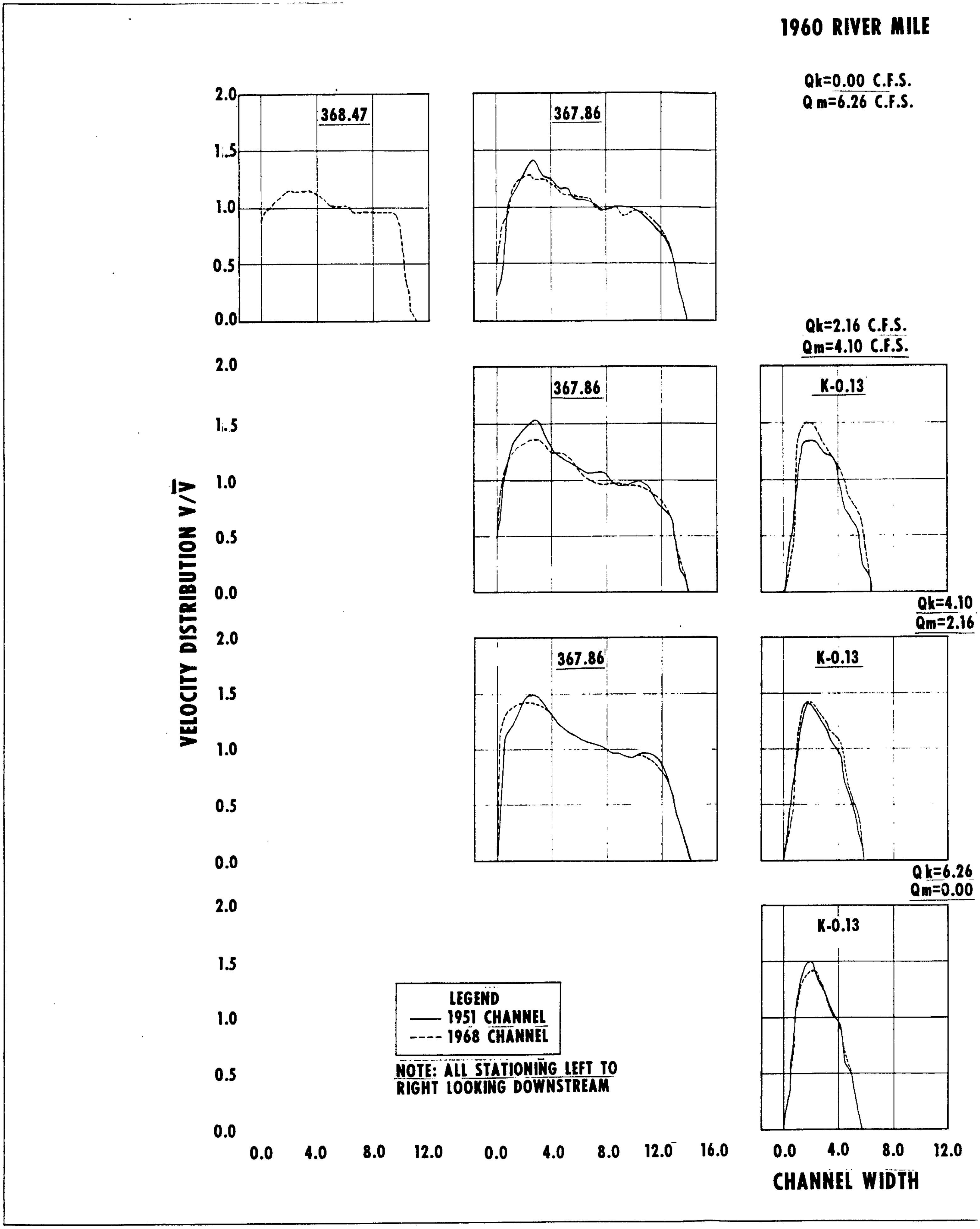
MISSOURI RIVER DESIGN STUDY
KANSAS CITY JUNCTION LOSS MODEL

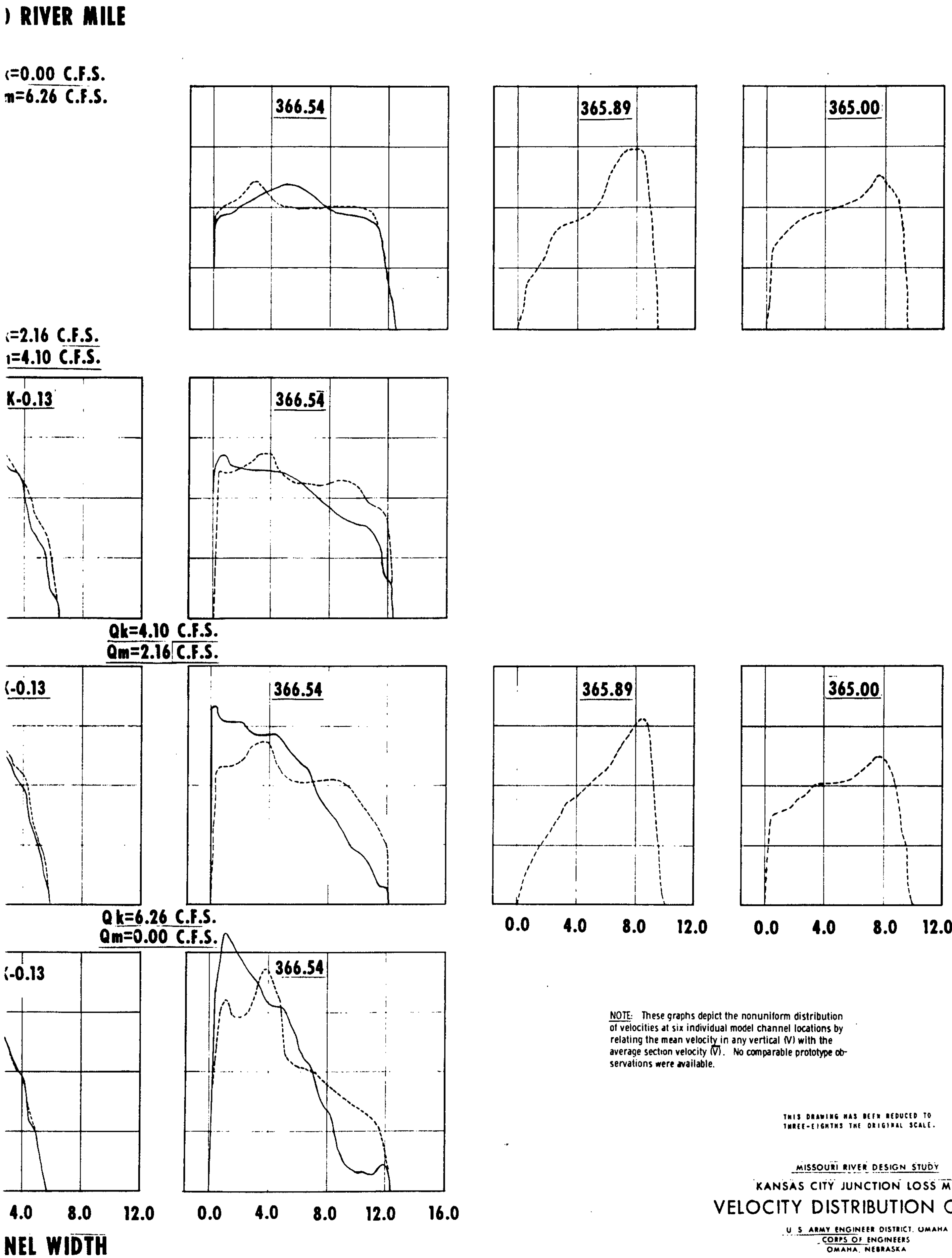
MODEL RATING CURVE AND JUNCTION LOSSES

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
AUGUST 1971

PLATE NO. 10

2


1960 RIVER MILE
Qk=0.00 C.F.S.
Q m=6.26 C.F.S.
368.47
367.86
Qk=2.16 C.F.S.
Qm=4.10 C.F.S.
367.86
K-0.13
Qk=4.10
Qm=2.16
367.86
K-0.13
Q k=6.26
Qm=0.00
K-0.13
VELOCITY DISTRIBUTION V/V̄
2.0
1.5
1.0
0.5
0.0
LEGEND
1951 CHANNEL
1968 CHANNEL
NOTE: ALL STATIONING LEFT TO RIGHT LOOKING DOWNSTREAM
0.0
4.0
8.0
12.0
16.0
CHANNEL WIDTH



NOTE: These graphs depict the nonuniform distribution of velocities at six individual model channel locations by relating the mean velocity in any vertical (V) with the average section velocity $(\bar{V})$. No comparable prototype observations were available.

THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

MISSOURI RIVER DESIGN STUDY

KANSAS CITY JUNCTION LOSS MODEL

VELOCITY DISTRIBUTION CURVES

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
AUGUST 1971

PLATE NO 11

2